FLAVORS OF MILK
A Review of Literature

By D. R. Strobel, W. G. Bryan, and C. J. Babcock

United States Department of Agriculture

Washington, D. C.

November 1953

CONTENTS

Page

FLAVORS OF MILK

A Review of Literature

D. R. Strobel, W. G. Bryan, and C. J. Babcock

INTRODUCTION

Off-flavor in milk is one of the major problems of the dairy industry. Innumerable experiments have been made, research reports have been published, and lectures and talks have been delivered on causes and correction but off-flavored milk remains an active subject. The programs of almost every dairy meeting and nearly every issue of the dairy journals contribute additional material on the subject.

An individual endeavoring to make a study of off-flavors in milk finds himself confronted with an apparently insurmountable maze of references. These references include articles based on experimentation, and articles based on personal opinions or secondhand information. The purpose of this review is to bring together brief summaries of the principal findings of more than 300 research reports and to provide a convenient reference to the articles based on experimentation on the flavor of milk.

Research work on flavors in manufactured products is not included in this report and research on individual milk components is included only when such research constructively adds to the general history of the subject. Although this publication is designed to establish a basis for an appraisal of the results of research to determine how much is known and what additional research is needed in this field, the review is confined primarily to a recording of existing research data and conclusions, including conflicting views.

This review is arranged under ten main headings. The first nine headings deal with the principally recognized off-flavors in milk and the tenth heading deals with miscellaneous off-flavors of milk. Feed flavor is reviewed first because it is the earliest recorded flavor defect. Weed flavor is second because it is closely associated with feed. The remaining off-flavors are reviewed in the order of their importance or association with each other. The results of the research under individual headings are presented in chronological order to show the development of findings in regard to each flavor factor.

I.—FEED FLAVORS

One of the earliest recorded references to off-flavors in milk deals with a feed flavor. In 1757, Bradley (37)[1/] was reported as stating that, near London, in the autumn it was customary to feed the cows with turnips—both fresh leaves and roots—and that the milk from these cows had a bitter

---

1/ Underscored numbers in parentheses refer to Literature Cited, p. 71.

flavor. It was suggested that the milk would not be bitter if the leaves were cut from the roots and held 2 or 3 days before feeding.

At the present time, nearly 200 years after the statements by Bradley (37) were reported feed still continues to be one of the main contributing factors toward off-flavored milk.

Alfalfa

In 1922, Gamble and Kelly (96) found that the feeding of 5 pounds of alfalfa silage per cow 1 hour before milking imparted a slight feed flavor to the milk. As the quantity fed was increased, the flavor defect increased in intensity until at a ration of 20 pounds the flavor of the milk was described as an "alfalfa silage" flavor. Aeration of the milk reduced the "slight" feed flavor and odor to "very faint." Aeration did not reduce strong off-flavor or odor to the point of acceptance of the milk. Feeding 10 pounds of alfalfa silage once daily 1 hour after milking produced a noticeable alfalfa-silage flavor in the milk. A ration of 15 to 20 pounds produced a decided feed flavor and odor. Aeration of the milk decidedly reduced the off-flavor. The experimental work indicated that alfalfa silage should be fed only after milking and that the milk should be aerated while still warm.

Babcock (18) reported, in 1923, that the feeding of green alfalfa to dairy cows at the rate of 30 pounds per cow 1 hour before milking produced very pronounced off-flavors and odors in the milk. When the quantity fed was decreased to 15 pounds, the off-flavors and odors were still present to an objectionable degree. He found it advisable to feed green alfalfa after milking and, when using alfalfa pasture, to remove the cows from the pasture 4 or 5 hours before milking. Proper aeration of the milk reduced the strong off-flavors and odors caused by feeding green alfalfa.

In 1932, Roadhouse and Henderson (250) found that feed flavor appeared in the milk 20 minutes after the ingestion of alfalfa juice used as a drench. The most pronounced feed flavor was present in the milk drawn 45 to 60 minutes after drenching. When green or dry alfalfa was fed to cows, the most prominent feed flavor was observed in the milk 2 hours after feeding.

Weaver et al. (308) reported, in 1935, that alfalfa hay fed less than 4 hours before milking had a pronounced effect on milk flavor. The effect was observed when the interval between feeding and milking was only $\frac{1}{2}$ hour. A 2-hour interval caused the most serious off-flavor in the milk. When alfalfa hay was fed 4 hours before milking, the flavor was entirely eliminated in the milk produced by some cows and scarcely discernible in the milk produced by other cows. The intensity of flavor increased as the amount of alfalfa hay fed was increased. The effect was found to be less serious with Holstein cows than with Jersey cows. Aeration of the milk removed some of the off-flavor. Cooling the milk was ineffective in removing the off-flavor. It was recommended that alfalfa be fed after milking or at sufficient intervals before milking.

In 1935, Roadhouse and Henderson (251) found that full rations of alfalfa hay and green alfalfa fed 1 to 2 hours before milking produced strong, undesirable feed flavors and odors in the milk. As the intervals between feeding and milking

increased, the intensity of the feed flavors decreased. A 5-hour interval between feeding and milking eliminated the off-flavor in the milk. A distinct and undesirable feed flavor resulted from feeding 5 pounds of alfalfa hay and 10 pounds of green alfalfa, 1 to 2 hours before milking. Similar results were reported in 1937 (252).

Anderson (6) reported, in 1936, that increasing the ration of alfalfa hay from 10 to 15 pounds with a corresponding reduction in corn silage eliminated the development of rancidity in milk. He referred to an experiment showing that machine-cured alfalfa hay contained a factor necessary for production of milk of good flavor.

Roadhouse (248), in 1937, concluded from a study that 10 pounds of alfalfa hay or 25 pounds of green cut alfalfa would give a distinct feed flavor to milk but that the off-flavor was most prominent when the feed was placed before the cow 2 hours before milking.

The effect of grazing cows on an alfalfa-bromegrass pasture was reported, in 1940, by Trout et al. (302) as a so-called soda, alkaline off-flavor in the milk. The intense off-flavor was found when cows were grazing heavily and being milked three times daily. It was found that alfalfa contributed more to the off-flavor than did the bromegrass. When the cows were kept off the pasture 7 hours prior to milking no feed flavors were noticeable in the milk.

MacCurdy and Trout (197) reported, in 1940, that feed flavors were noted in the milk when 0.4 pound of alfalfa silage per pound of milk produced was fed to cows 1 hour before milking. Alfalfa flavor in milk was lessened in intensity by pasteurization.

Nelson (219), in 1944, found that when alfalfa hay was fed a short time before milking, the milk generally had a flavor typical of that called "barny" by milk judges. The odor of the milk was also not unlike that of the interior of an unclean, poorly ventilated cow barn.

Barley

In 1929, the Bureau of Dairy Industry (10) reported experiments with barley infected with scab (*Gibberella saubinettii*). It was found that when the grain ration fed to dairy cows either before or after milking was 57-percent barley infected with *G. saubinettii*, it did not affect either the flavor or odor of the milk produced.

Green barley, in quantities required for satisfactory nutrition and as the sole source of roughage, fed to cows 2 hours before milking was reported, in 1935, by Roadhouse and Henderson (251), to impart an undesirable feed flavor to the milk. These authors also found that rolled barley fed alone in 5-pound quantities or more, 1 to 2 hours before milking, produced either a detectable flavor or off-flavor in the milk. However, it was believed that these flavors would not be noticed, in cold milk, by the average consumer.

Beet

Wing and Anderson (324) reported, in 1900, that there was no noticeable foreign odor or flavor in the milk from cows eating beet pulp.

In 1912, Reece (243) reported the results of feeding sugar beet slices to cows at four agricultural colleges in England. It was found that the milk showed no uncommon flavor of any kind while the slices were being fed.

Babcock (19) reported, in 1927, that dried beet pulp soaked and fed to cows one hour before milking, in quantities up to 30 pounds produced only a slightly abnormal flavor and odor in the milk. When fed in similar quantities immediately after milking the beet pulp had no effect on the flavor or odor of the milk. He also reported that sugar beets fed to cows, either before or after milking, in quantities up to 30 pounds had no effect on either the flavor or odor of the milk.

Dried molassed beet pulp gave rise to a taint in milk according to Cranfield and Mackintosh (62), in 1935. In pronounced cases, the off-flavor was described as "fishy" and in mild cases as "musty" or "egg-like." If the pulp were fed midway between milkings there was more likelihood of taint than if it were fed just before or during milking. Nine pounds per head in two feedings was found to be the maximum that could be fed without producing an off-flavor in the milk. It was noted that certain cows were more likely to produce tainted milk than other cows; that some types of dried beet pulp were more likely to produce tainted milk than other types; and that the off-flavor was more easily detected in heated milk than in non-heated milk. The "fishy" flavor appeared after the milk had been kept a few hours.

Roadhouse and Henderson (251), in 1935, found that dried beet pulp when fed 1 to 2 hours before milking, in quantities used by the average commercial dairyman, did not give milk sufficient flavor to make it undesirable to the average consumer. However, when fed in 5-pound quantities or more, 1 to 2 hours before milking, the beet pulp imparted either a detectable flavor or after-flavor to the milk.

In 1935, Trout and Taylor (306) reported results of a study of 1,700 samples of milk produced by cows fed beet tops. Intense beet top flavors were noted in the milk only when abnormal quantities (at least 25 pounds per day) of beet tops were fed; when the tops were of poor quality; or when frozen tops were stored in a poorly ventilated stable adjacent to the milking herd. Aeration of the milk appeared to render the beet top flavor less objectionable but did not eliminate it entirely. Pasteurization changed the flavor so that it could not be criticized as beet top flavor but such milk could not be classified as good in flavor.

In 1936, Davies (73) found that to decrease the possibility of a sporadic occurrence of a fishy off-flavor, molassed beet pulp should not be fed in a quantity exceeding 9 pounds per cow per day, and that this quantity should be divided into two equal $4\frac{1}{2}$ pound feedings and be fed at the time of milking. The equivalent of this quantity of beet pulp in beet tops would be roughly 60 pounds.

Cabbage

Babcock (20) found, in 1924, that when cows consume an average of 14.3 pounds of cabbage 1 hour before milking, objectionable abnormal flavors and odors were produced in the milk. An increase in the quantity of cabbage consumed from 14.3 pounds to 24 pounds increased to a marked degree the intensity of the off-flavor in the milk. He found that an average of 25 pounds could be consumed immediately after milking without resulting in off-flavors in the milk produced at the next milking. Proper aeration reduced strong off-flavors, and eliminated slight off-flavors.

Carrots

In 1927, Babcock, (19) reported that carrots in quantities up to 30 pounds fed to cows 1 hour before milking had only a slight effect on either the flavor or odor of the milk.

Citrus Products

In 1941, Garrett et al. (102) found that beet pulp and citrus pulp are about equal in their effects on the flavor of milk with the exception that a bitter flavor frequently appeared in the milk when cows were being fed citrus pulp.

In 1951, Tarassuk and Roadhouse (281) reported that dried citrus pulp (lemon and grapefruit pulp) and dried orange pulp when fed in quantities up to 4 pounds per cow 1 to $1\frac{1}{2}$ hours before milking did not impart an objectionable flavor to the milk. Feeding 5 pounds or more of dried orange pulp 1 to $1\frac{1}{2}$ hours before milking did impart an undesirable feed flavor to the milk.

Clover

In 1922, it was reported (11) that milk was returned by an Ontario milk plant because of a high acidity and sweet nauseating flavor. This off-flavor was reported as being caused by pasturing the cows on sweetclover freely during the summer. It was found that less trouble was experienced by dairymen who fed sweetclover pasture until noon and in the afternoon fed another type of pasturage, supplemented by some grain.

Gamble and Kelly (96), in 1922, found that the feeding of 5 pounds of sweetclover silage per cow 1 hour before milking imparted a detectable feed flavor and odor to the milk. When the quantity of sweetclover silage was increased to 15 pounds the feed flavor and odor of the milk became very objectionable. When fed after milking, 15 pounds of the sweetclover silage tainted the milk produced at the next milking sufficiently to be noted by the average consumer. Aeration of the milk diminished the off-flavor. Results of tests showed that sweetclover silage should be fed after milking and the warm milk should be aerated.

In 1935, Roadhouse and Henderson (251) found that a full ration of clover hay fed 1 to 2 hours before milking produced a strong, undesirable feed flavor and odor in the milk. When the clover hay was withheld during the 5-hour interval before milking, objectionable feed flavors and odors were eliminated.

Loosli et al. (195), in 1950, reported that milk of poor keeping qualities resulted during ladino clover feeding and that the clover appeared to be correlated with a low content of tocopherol in the milk fat.

Sheuring, et al. (271) reported in 1952 that flavor scores showed no clover flavor to be present in the milk produced by cows grazing on a winter pasture of ladino clover, fescue, and orchard grass up to 2 hours previous to milking.

Coconut

In 1935, Roadhouse and Henderson (251) reported that coconut meal fed 1 to 2 hours before milking, in quantities used by the average commercial dairyman, did not produce sufficient feed flavor to make the milk undesirable.

Corn

In 1897, King (177) demonstrated that when corn silage was fed a short time before milking, a sweetish odor was imparted to the milk. It was further demonstrated that when the silage was fed to cows just after milking, in the majority of cases, milks so produced could not be separated by the sense of smell from nonsilage milks. It was determined that silage odors enter milk more rapidly through the cow than by absorption from the air.

Knisely (178) found in 1903 that samples of milk from silage-fed cows had a more pronounced odor than samples coming from hay-fed cows. However, the odor was not disagreeable.

Fraser (93), in 1905, reported on 372 comparisons of milk from silage-fed cows and nonsilage-fed cows. Of the 372 comparisons, 60 percent of those tasting the milk favored the milk from silage-fed cows, 29 percent favored the milk from nonsilage-fed cows, and 11 percent indicated no preference. It was concluded that silage of good quality, when used in reasonable quantities with other feed, was one of the best feeds obtainable for dairy cows when pasture was not available. Bad or disagreeable flavor in the milk from cows fed silage was invariably caused by the improper feeding of the silage or by using spoiled silage. It was determined that all feeds of this nature should be fed after, and not before, milking.

In 1922, Gamble and Kelly (96) found that the flavor and odor of silage was largely imparted to milk through the body of the cow; that silage-tainted air may have some effect but it is relatively small even under extreme conditions; and that silage fed 1 hour before milking was so quickly absorbed that its taint was discernible in the milk. It was recommended that silage be fed immediately after milking. A quantity not exceeding 15 to 25 pounds of corn silage fed twice daily after milking was found to be the maximum that could be fed without imparting a discernible flavor and odor to the milk of cows of the productive capacity used in the experiment. Aeration of the warm milk permanently removed slight off-flavor and reduced in degree more pronounced silage flavor and odor in the milk.

In 1923, Babcock (18) reported that feeding green corn, 1 hour before milking, at the rate of 25 pounds proved to have but slight effect on either the flavor or odor of milk. The same quantity of green corn fed immediately after milking affected neither the flavor nor the odor of the milk.

Roadhouse and Henderson (251) reported, in 1935, that a full ration of corn silage fed 1 to 2 hours before milking produced strong, undesirable feed flavors and odors in the milk. When the feed was withheld during the 5-hour interval between milkings, objectionable feed flavor and odor were eliminated.

In 1936, Anderson (6) reported that increasing the ration of alfalfa hay from 10 to 15 pounds with a corresponding reduction in corn silage eliminated the development of rancidity in the milk.

In 1936, Roadhouse and Henderson (253) recommended that when an average of 5 pounds of corn silage is to be fed, consideration should be given to feeding it after milking. If a ration of 15 to 20 pounds is to be fed, it is always best to feed the silage after milking. These authors (252) reported in 1937 that an average of 18.9 pounds of corn silage per cow, fed previous to milking, caused a distinct and undesirable feed flavor in the milk. An average of 14.2 pounds per cow was less detrimental to the flavor of the milk but was considered objectionable.

Brueckner (49), in 1939, stated that on numerous occasions he had placed good-flavored milk in a silo overnight; added corn silage to good-flavored milk; and obtained milk from a cow which had been fed corn silage previous to milking. The milk which had silage added and the milk from the cow fed silage had a distinct silage odor and flavor. The good-flavored milk which was placed in the silo remained good flavored.

In 1940, MacCurdy and Trout (197) reported that feed flavors were noted in milk when 0.79 pound of corn silage per pound of milk produced was fed to the cows 1 hour before milking. Vacuum holder pasteurization and forced aeration holder pasteurization were superior to unaerated or aerated (by stirring) holder pasteurization in removing the off-flavor from the milk. These processes were also superior to flash pasteurization.

Cottonseed

Cottonseed meal fed 1 to 2 hours before milking, in normal quantities, was found by Roadhouse and Henderson (251) in 1935, to produce a milk that was not undesirable in flavor.

Cowpeas

Babcock (21), in 1925, reported that when cows consumed an average of 14.7 pounds (out of 15 pounds fed) of green cowpeas, 1 hour before milking, only slight abnormal flavors and odors were produced in the milk.

In 1927, Babcock (19) found that green peas and oats fed to cows 1 hour before milking, in quantities up to 30 pounds, produced only a very slightly abnormal flavor and odor in the milk. When fed after milking, there was no effect on either the flavor or odor of the milk.

Distiller's Grain

In 1904, Lindsey (194) reported that the flavor and keeping quality of the milk appeared in no way to be affected when distiller's grain constituted one-half of the daily grain ration.

Foxtail

Roadhouse and Henderson (251) found, in 1935, that when foxtail was fed to cows 2 hours before milking, in quantities required for satisfactory nutrition and as the sole source of roughage, undesirable feed flavor was imparted to the milk. Cows being grazed on foxtail should be removed from the pasture at least 5 hours before milk.

Grass

In 1936, Roadhouse and Henderson (253) reported that when cows have free access to Sudan grass pasture, they may be left on the pasture until just before milking without influencing the flavor of the milk sufficiently to be objectionable. These authors (252) reported similar results in 1937.

Garrett et al. (104) reported, in 1937, that a roughage ration which contained a high proportion of good quality molasses grass silage was superior to corn silage in its ability to produce milk of high color and better flavor. Garrett (97, 98) reported similar results after additional experimentation in 1938 and 1939.

When cows were changed from a roughage diet of molasses alfalfa silage to spring pasture, Bartlett (34) found, in 1940, that there was a drop in the flavor quality of the milk due to the presence of grassy flavor. He recommended winter feeding of all the grass or legume silage the cows would eat to produce a milk of high color and good flavor.

Garrett and Bender (103) reported, in 1940, that the milks produced by cows on molasses grass silage were of better initial flavor, held their good flavors in storage better, and withstood the destructive effects of soluble copper better than did the milks produced by cows on either corn silage or beet pulp.

Kale

Babcock (19) found, in 1927, that green kale fed to cows 1 hour before milking, in quantities up to 30 pounds, produced a very abnormal flavor and odor in the milk. When fed immediately after milking, green kale had practically no effect on either the flavor or odor of the milk.

Oats

In 1927, Babcock (19) reported that green oats and peas fed to cows 1 hour before milking, in quantities up to 30 pounds, produced only a very slightly abnormal flavor and odor in the milk. When fed after milking, green oats and peas had no effect on either the flavor or odor of the milk.

Roadhouse and Henderson (251) found, in 1935, that wild oats fed to cows 2 hours before milking imparted undesirable feed flavors to the milk when fed as the sole roughage and in sufficient quantity for satisfactory nutrition.

Potatoes

Babcock (20), in 1924, found that when cows consume an average of 14.8 pounds of potatoes 1 hour before milking, slightly abnormal flavors and odors may be produced in the milk. The off-flavors and odors are very slight, however, and would seldom be perceived by the average consumer of the milk. An increase in the quantity of potatoes consumed 1 hour before milking to 29.3 pounds did not increase the abnormal flavors and odors produced in the milk. When an average of 28.7 pounds of potatoes was consumed immediately after milking no effect was produced on the flavor or odor of the milk.

Pricklypear

In 1915, Woodward et al. (327) reported that the feeding of pricklypear had no appreciable effect on the flavor or keeping quality of the milk. According to the authors, experiments were conducted for periods long enough to show conclusively that pricklypear was a good and palatable feed for dairy cows.

Pumpkin

Babcock (19), in 1927, found that pumpkins fed to cows, either before or after milking, in quantities up to 30 pounds had practically no effect on either the flavor or odor of the milk.

Rape

In 1927, Babcock (19) reported that rape fed to cows 1 hour before milking, in quantities up to 30 pounds, produced a decidedly abnormal flavor and odor in the milk. When fed immediately after milking, rape had practically no effect on either the flavor or odor of the milk.

Rye

Babcock (21), in 1925, found that when dairy cows consumed 15 pounds of green rye, 1 hour before milking, only slight abnormal flavors and odors were produced in the milk. An increase in the quantity of green rye consumed 1 hour before milking, from 15 to 30 pounds, increased to a slight extent the abnormal flavors and odors in the milk. However, the slight off-flavors and odors were not likely to be objectionable. The feeding of 30 pounds of green rye immediately after milking had practically no effect on the milk produced at the next milking.

In 1944, Trout and Harwood (301) observed that Balbo-rye pasture did not have the adverse effect on the odor of milk as did common rye. The offensive odor characteristic of milk from cows pastured on common rye at certain growth stages, variously described as neutralizer, soapy, or even fishy, was not noted in milk from cows pastured on Balbo-rye. The off-odor in milk caused by pasturing Balbo-rye may be described as slightly grassy and resembling somewhat the off-flavors in the milk from cows milked soon after removal from bluegrass pasture.

Safflower

In 1929, the Bureau of Dairy Industry (10) reported on studies made to determine the effect of safflower oil meal on the flavor and odor of milk. The studies showed that the grain ration fed to dairy cows either before or after milking might consist of 33-1/3 percent of safflower oil meal without affecting either the flavor or odor of the milk. No abnormal flavors which could be attributed to safflower oil meal developed during the aging of the milk for 5 days at 5° C.

Soybean

Woll and Humphrey (325) reported in 1904 that soybean silage imparted a pronounced poor flavor to the milk. The silage was fed after milking; the cows were kept in a modern, sanitary, ventilated, and lighted stable; the mangers were cleaned out before milking; and the milk was removed from the stable as soon as drawn.

Gamble and Kelly (96) reported, in 1922, that soybean silage fed 1 hour before milking, even in such small quantities as 5 pounds per cow, affected the flavor and odor of the milk. An increase in the quantity fed increased the feed flavor of the milk. It was stated that soybean silage should be fed after milking.

In 1927, Babcock (19) found that green soybeans fed to cows 1 hour before milking, in quantities up to 30 pounds, had a tendency to improve the flavor and odor of the milk.

Nevens and Tracy (221) reported, in 1928, that neither high-quality, nor poor-quality moldy soybean hay fed to cows had any effect on the flavor of the milk. Ground soybeans, comprising 10 to 25 percent of the concentrate mixture, were likewise without effect on flavor of the milk.

Roadhouse and Henderson (251) found, in 1935, that soybean meal fed 1 to 2 hours before milking, in quantities used by the average commercial dairyman, did not give milk sufficient flavor to make it undesirable to the average consumer.

Bartley et al. (35) found, in 1950, that neither soybeans nor soybean hay when fed to cows adversely affected the flavor of the milk.

In 1950, Frye et al. (95)reported that there was no indication that cracked soybeans produced an undesirable flavor in milk when constituting approximately 11 percent of the concentrate mixture fed to cows.

Sunflower

Arnett and Tretsven (15) reported, in 1917, that the milk from cows fed sunflower silage had no objectionable flavors and no change in the milk could be detected.

Tankage

In 1936, Olson et al. (227) found that the feeding of tankage in the grain ration in quantities as high as 50 percent by weight appeared to have no effect on the flavor of the milk. Even when fed 1 to 2 hours prior to milking, there was no effect on the milk.

Turnip

In 1829, Harley and Ridgway (141) reported a method to prevent milk from tasting of turnips. These authors recommended that a few teaspoonfuls of a strong solution of potassium or sodium nitrate be put in the milking pail prior to milking. Common turnips and cabbages were reported as giving a strong taste to milk. Aberdeen yellow turnips had little effect, and Swedish turnips had no effect on the flavor of milk. Steaming of the vegetables before they were fed was stated as the most effective way of preventing off-flavors in the milk.

Dean (78) indicated, in 1897, that pasteurizing and adding starter would overcome the turnipy flavors in milk and butter.

Babcock (22) reported, in 1923, that feeding turnips to dairy cows at the rate of 15 pounds 1 hour before milking produced objectionable off-flavors and odors in the milk. An increase from 15 to 30 pounds of turnips increased to a very marked degree the off-flavors and odors in the milk. Feeding turnips at the rate of 30 pounds immediately after milking had but little detrimental effect on the flavor and odor of the milk. Proper aeration eliminated the slight off-flavors and reduced the strong off-flavors.

General

In 1928, Babcock (23) outlined the following measures to prevent feed flavors in milk: Feed just after milking all material likely to taint milk; properly ventilate cow stables; aerate and cool the milk.

Garrett (97) stated, in 1938, that it had been shown that green feeds produced a better flavored milk than did dry feeds.

Babcock (24) stated, in 1938, that investigators had shown that many feeds impart their flavor to milk, the intensity of the flavor depending on the character of the feed, quantity consumed, and the time of consumption in relation to the time of milking. It was noted that feed flavors enter milk mainly through the body of the cow and in most cases these flavors are not imparted to the milk except for a few hours after feeding. Proper aeration of the milk eliminated slight feed flavors and reduced the intensity of strong feed flavors. It was recommended that highly flavored feeds be fed immediately after, never just before, milking.

In 1939, Davies (72) reported that milk production was not affected when the dairy herd was taken off pastures for 3 hours before the afternoon milking in order to control feed flavor. It was found that it was not necessary for this procedure to be continuous but that it could be changed to meet the condition of the pastures.

Bartlett (34), in 1940, recommended the following procedures for winter feeding to produce high color and good flavor of the milk: (1) Feed all the grass or legume silage (cut before maturity and properly preserved) that the cows will eat; (2) feed all roughages immediately after the entire herd has been milked to avoid feed or silage flavors in the milk; (3) clean-up spilled silage and keep passage from barn to silo closed to prevent permeation of the barn air with silage odors; (4) air out the barn 30 minutes before milking.

In 1950, Frye et al. (95) determined that the correlation coefficients between milk and fat yields and the occurrence of feedy flavors in milk was nonsignificant. The correlation coefficient between age and the occurrence of feedy flavor was nonsignificant.

Dahlberg et al. (64) provided evidence that, in 1953, feed continued to be one of the main contrubuting factors to off-flavored milk. They showed that of 169 samples of fresh pasteurized milk, collected in 8 cities with populations of 100,000 or more, 127 samples, or 75 percent, had a feed flavor.

II.-WEED FLAVORS

Closely associated with feed flavors are weed flavors. Through weed-infested pastures, or weeds mixed in the hay, silage, or the concentrate portion of the ration, cows often ingest enough weeds to produce an off-flavor or taint in the milk they produce. The weed that has received the most attention from investigators is wild onion or garlic. The effect of this weed was first reported (37) in 1757. That weed flavor is still an important problem was indicated in 1951 by Aurand and Moore (16) who reported that three different mineral supplements, advertised to prevent weed flavor in milk, when fed to cows, failed to do so.

Bitterweed

Babcock (25), in 1929, reported work with bitterweed. He found that cows must consume $4\frac{1}{2}$ to 5 pounds of bitterweed 1 hour before milking, or $2\frac{1}{2}$ to 3 pounds ($\frac{1}{2}$ pound at 1-hour intervals) to within 2 hours of milking, before its effect would be noted by a very slightly bitter taste in the milk. As the quantity of bitterweed consumed was increased, the intensity of the bitter flavor in the milk was increased. When more than 7 pounds was consumed, bitter milk was produced and more than 9 pounds produced a very bitter milk. Regardless of the degree of bitterness, the milk had a normal odor. When bitter milk was separated, the bitter flavor was more pronounced in the skim milk than in the cream or the whole milk. Also, unlike the flavors caused by most feeds and weeds, the off-flavor caused by consumption of bitterweed in the cows' rations did not disappear from one milking to the next. The off-flavor was present in milk produced 24 hurs after the cows had consumed 10 pounds of the weed.

In 1929, MacDonald and Glaser (202) determined that the bitter substance of bitterweed was found in all parts of young plants, but in mature plants mainly in the leaves and flower-heads. The bitter substance was crystalline, nonvolatile, nearly colorless, and odorless. It was soluble in water but insoluble in fat and in mineral oil. Because of these properties, it dissolved in the water, or serum, of milk but not in the fat.

Weathers (307), in 1933, reported a test to determine the presence of the bitter substance imparted to milk by the bitterweed. The substance was detected by the characteristic orange-red color that developed when contaminated milk was treated directly with solutions of picric acid and sodium hydroxide. The quantitative determination of the bitterweed principle could be accurately made on the alcohol-ether extracts of centrifuged milk by the use of standards of purified bitter crystals, or by the use of either creatinine or picramic acid standards.

Carrotweed

In 1939, carrotweed was reported (13) as a serious cause of taint in milk.

Fanweed

In 1944, Nelson (219) reported that when ground fanweed seed was fed immediately after milking, in amounts up to 9 percent of the total grain ration, the fanweed flavor was not present in the milk produced at the next milking. However, when fed within an hour before milking, the milk was unfit for sale.

Land Cress

In 1938, Marryatt (207) reported a cress flavor in milk caused by land cress. The flavor was found to be reduced by preventing cows from eating land cress within 4 hours before milking.

Allo (2), in 1940, reported experiments that proved that cress taint in milk could definitely be overcome by controlled grazing.

Mayweed

In 1926, Procter (235) found that mayweed (chamomile) did taint milk when fed to cows in sufficient quantity. The tainting principle was determined to be a chemical substance or substances which when added mechanically to milk or when drenched orally to a cow would give the milk the typical off-flavor.

Hansen (139), in 1929, reported that mayweed was capable of imparting an off-flavor and odor to milk.

Peppergrass

In 1944, Pratt (234) found that ensiling peppergrass with molasses as a preservative produced a palatable silage which after fermentation had no peppergrass flavor. He concluded that crops containing peppergrass might be ensiled without fear that off-flavor would result in the milk or milk products.

Ragweed

In 1929, Hansen (139) and Lucas (196) recognized that ragweed eaten by cows was one of the principal causes for weed flavors and odors in the milk.

Wild Onion or Garlic

In 1757, Bradley (37) was reported as stating that when cows were fed garlic their milk would be found to have a garlic taste and scent.

Russell (261), in 1897, stated that the volatile principle in onion and some other garden vegetables could be recognized in the expired breath of the cow and in its milk within a short time after the substance was eaten. He recognized that different volatile odors are diffused by means of the circulation throughout the body tissues and therefore it might be expected that a fluid having such great absorptive properties as milk would be saturated with those substances.

In 1914, Ayers and Johnson (17) reported that they had experimentally removed onion or garlic flavor from milk by blowing air through it at 145° F. The off-flavor was entirely removed in 30 to 60 minutes.

Babcock (26), in 1925,reported that garlic flavor and odor were detected in the milk when the samples were taken 1 minute after feeding garlic. The

intensity of the garlic flavor and odor increased as the time interval between feeding the garlic and taking the milk samples increased until at 10 minutes a high degree of intensity was reached. Very objectionable garlic flavor and odor were present in milk when the cows consumed $\frac{1}{2}$ pound of garlic 4 hours before milking. As the time interval increased, the off-flavor decreased until at 7 hours it had practically disappeared from the milk. Strong garlic odor and flavor were found in the milk drawn 2 minutes after the cows inhaled garlic for 10 minutes. At 90 minutes between inhalation and milking, the off-flavor and odor had disappeared. Garlic odor was readily perceived in samples of blood drawn 30 minutes after feeding the cows 2 pounds of garlic tops, and strong garlic odor was present in the blood drawn 45 minutes after such feeding. This definitely established that feed and weed flavors enter milk mainly through the body of the cow.

Procter (235), in 1926, recognized that garlic or wild onion tainted milk.

MacDonald and Crawford (200), in 1927, reported that in experiments with onion-flavored milk it was found that the substance responsible for the disagreeable flavor and odor was carried almost entirely by the milk fat. They explained the use of mineral oil to remove the onion flavor. These authors (201) reported further experimentation in 1927. They found that one washing with 1 part of mineral oil to 10 parts of milk would remove onion odor but that two washings were needed to remove all of a strong onion odor and taste. The oil was separated from the milk and purified for reuse.

In 1927, Trout (298) stated that the oil treatment was an effective control measure for the onion or garlic off-flavor in milk.

MacDonald and Jacob (203), in 1928, reported that inhalation of the volatile substances from fresh wild garlic tops produced a strong garlic flavor and odor in the blood and milk in a very short time. When administration of the garlic was arranged to eliminate as far as possible the inhalation factor, the time required for the acquisition of the garlic flavor and odor by milk was greatly increased and the intensity of the flavor and odor was markedly diminished.

In 1929, Hansen (139), recognized garlic or onion as among the principal causes of weed flavors and odors in milk.

MacDonald et al. (199), in 1930, stated that the process of mineral oil treatment of onion-flavored milk to remove objectionable flavor permitted an almost complete removal of the oil from the milk. It was concluded from evidence presented that the milk suffered no deleterious effects from the process.

Wylie (329), in 1937, reported that the most practical method of onion-flavor control in milk was pasture management.

In 1951, Aurand and Moore (16) stated that several manufacturers of mineral dairy supplements had advertised their product as preventing weed flavors in milk. They reported that experiments with three different mineral supplements

fed at the rate recommended by the manufacturers to cows on onion-infested pasture (supplemented in one of three trials by a pound of chopped onions per cow per feeding) showed that: (1) None of the supplements prevented the occurrence of onion flavor; and (2) although two of the supplements improved the quality of milk, the difference was of such small magnitude that only competent judges could detect it.

Miscellaneous

Hansen (139) and Lucas (196), in 1929, recognized the following as causing undesirable weed flavors and odors in milk: Beardtongue; boneset; buckhorn, dogfennel; foxglove; horseweed; marestail; wild lettuce; and wild tansy. Hansen stated that when buttercups are grazed in abundance, there was not only danger of a strong flavor but a reddish hue might be imparted to the milk. He also stated that marestail was found to cause a bitter flavor and a peculiar odor in the milk.

Dice (79), in 1944, listed three ways of avoiding or correcting off-flavors in milk and milk products, as follows: (1) Careful herd management--feed an adequate ration and keep cows off weedy pastures from 3 to 8 hours before milking; (2) good pasture management to control the weeds; (3) vacuum pasteurization.

III.-OXIDIZED FLAVOR

None of the other off-flavors of milk has been so widely investigated and discussed as has the one now commonly known as "oxidized." One of the earliest references to this defect was recorded by Golding and Feilman (110), in 1905. These workers traced an alkaline, mealy off-flavor in milk to exposed copper on the surface of a tinned farm cooler. By experiment, they showed that 600 milliliters of fresh milk left standing over a 15 by 11-centimeter piece of clean copper foil developed a peculiar mealy flavor in 16 to 18 hours. They concluded that copper was acted on by milk, especially in the presence of air, and that small quantities of the metal went into solution in the milk. They further concluded that the off-flavor appeared to be due in part to the development of micro-organisms in the presence of copper.

Since 1905, "oxidized" flavor has been described in the literature as "cappy," "papery," "cardboard," "pulpy," "oily," "tallowy," "chalky," or "soapy." Many of these terms are used interchangeably, at the present time, to describe progressive steps in the oxidative process. It is now generally agreed that the ultimate defect results from an oxidation of the milk fat or an associated milk fat component. However, discussions continue as to the actual oxidative process involved and the actual component part or parts affected. Research is being continued in an effort to determine the best means of preventing the defect. That such research is needed was shown by the report, in 1953, of Dahlberg et al. (64) that out of 169 samples of fresh pasteurized milk, collected in 8 cities with populations of 100,000 or over, 29 samples, or 17 percent, had an oxidized flavor. After holding 7 days at 33° F., 67 percent of the samples were oxidized. Such a prevalent and widely investigated defect has led to much tangent research or research not directly concerned with the defect itself. For example, in 1936, it was determined that ascorbic acid or vitamin C was associated with the development of the oxidized flavor. As a result much research has been conducted and much more is being conducted to determine the exact relationship between these two factors. Since the relationship was noted, research also has been conducted to determine the factors that affect the ascorbic acid or vitamin C content of normal milk and its relation to the other constituents of milk. This type of research is partly reviewed in this publication.

Metallic Contamination

As stated above, metals were first associated with oxidized flavor in 1905 (110).

In 1927, Okuyama (223) reported the results of an investigation undertaken when one farm's milk developed a "cap" or "pulpy" taste. Samples of the producer's milk were taken at every point from cow to bottle. Care was taken to prevent contact of the milk with the cap. The samples of milk were immediately iced, held

in ice box, and samples for flavor at 24-, 48-, and 72-hour intervals. From the cooler on, the samples had an off-flavor. The source of the off-flavor was traced to exposed copper on the cooler surface. After the cooler was retinned, the off-flavor was eliminated.

Mattick, (211), in 1927, reported that oiliness was due to the catalytic oxidizing action of exceedingly minute quantities of copper being taken up by the milk at various points in its handling. It was stated that oiliness was not identical with other flavors induced by larger, but still very small, quantities of the metal. The reaction was found to be dependent to a large extent on free access to molecular oxygen.

In 1931, Guthrie et al. (133) found that copper, copper alloys (ambrac, brass, bronze, monel metal, nickel, silver, and Waukesha metal), showed weight losses when exposed to sweet milk and produced oxidized flavors in all samples of milk. Tin-plated and chromium-plated copper were unsatisfactory in preventing copper contamination due to mechanical wearing away of the plating. Chromium alloys showed little or no weight losses in milk, but in some milks these alloys induced a slight oxidized flavor. Chromium-nickel alloy, aluminum, glass enamel, and carefully tin-plated metals showed no weight losses, remained clear, and did not induce oxidized flavors. Aeration by continuously bubbling air through the milk during pasteurization increased the tendency toward development of oxidized flavors.

Tracy and Ruehe (296), in 1931, stated that the development of tallowy flavor in milk was closely associated with metal contamination. They concluded that milk should not be brought into contact with either iron or copper surfaces. Benedict nickel was also reported as having a detrimental effect on milk. Glass and Allegheny metal had practically no ill effects on milk flavor.

Button (52), in 1933, reported that outbreaks of cardy milk in five New Jersey plants had been definitely traced to exposed copper surfaces in milk-processing equipment.

In 1933, Davies (74) found that 1.5 p.p.m. of total copper in milk of good hygienic quality stored at 32° to 40° F. was sufficient to cause a detectable oxidized-fat flavor within 24 hours. Natural copper content of 100 samples of milk from various parts of Great Britain ranged from 0.30 to 0.75 p.p.m. It was found that the cooler was the piece of equipment responsible for the greatest increase in the copper content of milk. Copper was also added by the pasteurizer. In all cases where the cooler or pasteurizer was responsible, retinning or replacing stopped the oily off-flavor. It was generally found that an increase in copper content of the milk was usually accompanied by an increase in iron content.

Brown et al. (43) reported, in 1936, that amounts of copper ranging up to 2.5 p.p.m. added to milk pasteurized by the "low-long method" caused a more frequent and more intense development of oxidized flavor than did the same amount of copper added to the milk prior to pasteurization. Samples of raw milk contaminated with 2.5 p.p.m. of copper tended to develop oxidized flavor of about the same intensity as that occurring in samples from the same supply of milk identically contaminated after pasteurization. However, the off-flavor developed in the raw milk was of a greater intensity than that produced in samples from the same supply of milk identically contaminated before pasteurization.

In 1937, Thurston (283) reported that copper and iron must be in solution to cause oxidized flavor in milk. He stated that it appeared that these were the only metals capable of causing oxidized flavor development in milk.

Nelson and Dahle (216) found, in 1939, that the spontaneous and copper-induced oxidized flavors in milk are identical. Judges were unable to distinguish any difference except in intensity.

In 1939, Gould (111) reported that the heating of milk momentarily to 80° to 82° C., or above, prevented the development of an oxidized flavor as induced by 2.8 p.p.m. of ferrous iron. This occurred irrespective of whether the iron was added before or after the heat treatment. The "critical" temperature is different for milk containing added ferrous iron than that for milk containing added copper. This is due to the differences in the sulphide combining abilities of these metals, to differences in their abilities to form complexes with the substance supplying the heat labile sulphur, or to differences in their oxidizing property. It was reported that the liberation of sulphides prevented the development of oxidized flavor.

Henderson and Roadhouse (144), in 1940, found that nickel, lead, and zinc did not influence the oxidation of ascorbic acid and did not cause oxidized flavor in the milks pasteurized in contact with pure strips of these metals.

Greenbank (121), in 1940, reported that his results indicated that copper was more active as a catalyst than was ferrous iron.

Garrett (99) reported, in 1941, that divalent manganese added to milk contaminated with copper or iron completely inhibited or greatly retarded the

development of oxidized flavor. Metallic manganese exhibited a similar effect. Aluminum did not prevent the development of the oxidized flavor in copper-contaminated milk.

Bartley et al. (35), from experiments conducted from November through May 1950, concluded that rusty tin containers increased the susceptibility of the milk to oxidation.

In 1953, Willard and Gilbert (323) stated that, although stainless steel equipment was advised for milk processors as a preventive of oxidized flavors, few experiments had brought to light the extent to which alloy metals containing copper produced an oxidizing effect in the hot milk side of milk processing. They reported that, for several years, pasteurized milk at the University of Wyoming creamery had become oxidized after 2 days in storage unless an antioxidant had been added to the milk before pasteurization. By experimentation, they found the milk being contaminated by soluble copper obtained from two pumps, the strainer-cage, the strainer inner tube, and the strainer cap but not from the stainless steel pipe cap. Samples of milk were heated to 140° F. in contact with the creamery equipment and the milk was analyzed for copper solubility. Wherever considerable soluble copper was found, strong oxidized flavor developed in milk after 4 days storage. More of the copper was found in the cream than in the skim milk after separation and oxidized flavor was produced in greater intensity in the cream. These authors recommended that care be taken in the purchase of creamery equipment so as to avoid the use of metal that contains appreciable amounts of soluble copper.

Cows as Source

Guthrie and Brueckner (130), in 1933, reported on samples of milk, from 155 cows in five herds, examined for oxidized flavors after pasteurization and storage in brown glass bottles. They found that 21 percent of the 155 cows consistently gave milk that developed distinct oxidized flavors at the end of a 3-day storage period. Approximately 10 percent of the cows produced milk which developed only slight oxidized flavors. The percentage of cows in the herds whose milk developed distinct oxidized flavors ranged from 6 to 28 percent. These authors reported that apparently no relation existed between the breed, period of lactation, or age of the cow, and the development of oxidized flavor in the milk.

In 1935, Chilson (54) found that about 25 to 30 percent of the cows in the Cornell herd gave milk during the winter and spring months which developed an oxidized flavor when pasteurized and stored in glass at a low temperature. The milk of individual cows showed a great variation in its susceptibility to oxidation. It was found that it was not necessary for the milk of some cows to come in contact with metals or their salts for the oxidized flavors to develop, but the presence of such salts greatly accelerated the reaction.

Tomlinson (290), in 1940, reported that no samples of milk from individual cows could be found which would develop the oxidized flavor without added copper. However, samples were found where even 0.1 p.p.m. of copper made them susceptible.

Corbett (58), in 1942, reported that milk from individual cows varied in its susceptibility to the development of oxidized flavor. The variation was correlated with the stage of lactation and age of the animal, but only slightly correlated with

season of the year (March through September), and the breed of the cow. The quantity of milk and fat produced weekly was not related to the development of the off-flavor. Similar results were reported by Corbett and Tracy (59), in 1943. Milk from Ayrshire cows appeared slightly less susceptible than that from other breeds of cows. Milk from the first part of the lactation period was more susceptible to off-flavor than was milk from the latter part of the lactation period. Milk from heifers was much more susceptible than was milk from older cows.

Feed as a Factor

In 1934, Henderson and Roadhouse (145) reported that milk from cows on submaintenance rations showed increases in the percentages of unsaturated fats and increased susceptibility of the fat to oxidation.

Anderson (7), in 1937, found that a change from the production of good milk to milk which acquired an oxidized flavor could be brought about by changing the hay fed to the cows from good machine-dried alfalfa hay to poor field-cured alfalfa hay. The cows would again produce milk of good color and flavor when fed a good quality hay or a poor quality hay plus a small quantity of carrots.

The spontaneous oxidized flavor of cow's milk was influenced by the feed of the cow according to a report by Dahle and Palmer (71), in 1937. Green feeds, such as pasture, green alfalfa, and clover, inhibited the production of the off-flavor in milk. Breed of cows, stage of lactation, chlorine-lactose ratio, and leucocyte content of the milk had no influence on the occurrence of spontaneous oxidized flavor.

In 1937, Garrett (100) found that milk produced by cows on pasture feeding was of finer flavor than milk produced by cows under winter feeding conditions as measured by the disappearance of tallowy flavor when the cows received green feed. When cows produced tallowy flavor under both conditions the intensity of the undesirable flavor was far less when the cows were on pasture.

Brown, et al. (44), in 1937, found that dry feeding increased the tendency for oxidized flavor to develop in milk, and grazing on fresh pasture decreased the tendency. There was considerable variation among individual cows with respect to the tendency for oxidized flavor to develop in their milk. However, mixed milk (5 to 8 cows) never developed oxidized flavor when no copper or iron was added. The feeding of 1 quart per animal daily of either tomato or lemon juice to cows on dry feed greatly reduced the susceptibility of their milks toward the development of oxidized flavor. Pure crystalline ascorbic acid fed at the rate of one-half gram daily also greatly decreased the tendency for oxidized flavor to develop. It was concluded that vitamin C in the rations of dairy cows may reduce or entirely eliminate the susceptibility of their milks toward the development of oxidized flavor.

In 1938, Hening and Dahlberg (146) concluded that the feeding of mangels or beet pulp in no way prevented or increased the susceptibility of milk toward the development of oxidized flavor.

Brown et al. (45) reported, in 1939, that ascorbic acid fed to cows at the rate of 1 gram per day reduced considerably the tendency for metal-induced oxidized flavor to develop although it did not materially increase the ascorbic acid content of the milk. Carotene fed at the rate of 350 milligrams per day greatly reduced the tendency for metal-induced oxidized flavor to develop and resulted in an increased amount of carotene in the milk. However, it was concluded that the mechanism whereby oxidized flavor was developed spontaneously was influenced by some factor or factors other than a ration low in carotene.

Hening and Dahlberg (147), in 1939, found that the flavor of fresh milk and its keeping qualities, as indicated by the percentage occurrence of oxidized flavor and numerical score in aged milk, were not influenced by the level of feeding (10 and 20 percent below standard; 10, 20, and 30 percent above standard; control group at Morrison standard level). The occurrence of oxidized flavor was considerably less in the summer months than in winter months, but there was no definite correlation between the exact period of feeding green cut legumes and the occurrence of the off-flavor in the milk.

The feeding of grass silage prevented the development of oxidized flavor in milk when it was not contaminated with soluble metal, and greatly retarded the development and lessened the intensity of the off-flavor when soluble copper was added as reported by Garrett et al. (105), in 1939.

In 1939, Whitnah et al. (322) found that low carotene intakes were regularly associated with milk which developed oxidized flavor, and that high carotene intakes prevented or remedied the defect. However, these authors concluded that the level of carotene intake was possibly not the only factor determining the tendency of the milk to develop oxidized flavor.

Beck et al. (36), in 1939, reported that the development of oxidized flavor in raw milk was effectively prevented by feeding as little as 206 milligrams of carotene per head daily to cows that had been consistently producing milk with this off-flavor.

Martin et al. (210) in 1940, reported that the feeding of vitamin A at 30,000 or 90,000 International Units for 10 days or 300,000 International Units for 20 days to cows on winter rations reduced the incidence of oxidized flavor and improved somewhat the flavor score of copper-contaminated milk. Feeding 1/6 to 1/3 gram daily of carotene in addition to the vitamin A feeding reduced the intensity of the copper-induced oxidized flavor. Seven days of pasture feeding, in most instances, eliminated the copper-induced oxidized flavor in stored pasteurized milks.

Greenbank (121) reported, in 1940, that the development of the oxidized flavor in milk was not always inhibited by feeding green feed. However, he stated further that its beneficial effects were indicated by the fact that in every case there was a decrease in flavor intensity by the end of the fifth week on pasture.

In 1941, Garrett et al. (102) reported that legume and grass silages produced milks with greater resistance toward the development of oxidized flavor than did corn silage, beet pulp, or dried citrus pulp. Alfalfa silage was equal to or better than pasture in producing milk with high resistance toward the development of oxidized flavor. The difference in resistance toward the off-flavor between molasses grass silage and phosphoric acid grass silage was not significant.

Brown et al. (41) found, in 1941, that the feeding of 1 pound per day of coconut oil in the daily ration of a dairy cow reduced slightly the intensity of the oxidized flavor developed by copper, and decreased slightly the iodine number of the butterfat. The feeding of 1 pound daily of crude or refined soybean oil increased greatly the iodine number of the resulting butterfat and increased the susceptibility of the milk to metal-induced oxidized flavor.

In 1941, Brown et al. (46) reported that the feeding of high-quality alfalfa hay together with alfalfa leaf meal greatly reduced or eliminated the tendency for metal-induced oxidized flavor to develop. The feeding of brown, leafy alfalfa hay resulted in a decreased carotene content in the milk but did not increase the intensity of the oxidized flavor. The results indicated that the amount of carotene in butterfat may not be the substance responsible for the reduction in susceptibility of milk to oxidized flavor. It appeared that some substance or substances associated with carotene probably had a greater effect than did the carotene itself.

Babcock and Haller (31), in 1943, found that the feeding of molasses-alfalfa silage, straight alfalfa silage, soybean silage, or corn silage had no significant effects on the copper tolerance of the milk produced.

The milk of four cows fed cod-liver oil by Guthrie (125), in 1946, became oily and on standing developed either a "goaty" or an oxidized flavor. In a second experiment the milks of four cows became oxidized apparently as the result of administering cod-liver oil either in the feed or by drenching.

In 1952, Krukovsky and Loosli (184) found that a tocopherol supplement of 1 to 2 grams daily to a standard ration for cows could not be depended on to maintain the tocopherol content of the fat and to prevent or correct oxidized flavors in the milk under all conditions.

Composition Factors

Many of the constituents of milk have been studied to determine their relationship to the development of the oxidized flavor. The constituent of milk that has been most thoroughly studied is vitamin C or ascorbic acid.

Vitamin C, Ascorbic Acid

In 1935, Chilson (54) reported that the addition of 50 to 60 milligrams of ascorbic acid per liter of milk would prevent development of the oxidized flavor for 7 days in milk which otherwise would develop a pronounced oxidized

flavor. All vitamin C was found to be oxidized by the time the oxidized flavor was detectable.

Sharp et al. (269), in 1936, found that the addition of 100 milligrams of ascorbic acid per liter of milk greatly retarded the development of the oxidized flavor in milk. There was a positive correlation between the rate of oxidation of ascorbic acid and the rate of the development of the oxidized flavor.

Anderson (8) stated, in 1936, that vitamin C, ascorbic acid, was not the factor responsible for good-flavored milk since carrots, low in vitamin C, produce good milk whereas cabbage, high in vitamin C, does not produce good milk.

Dahle (66) noted, in 1936, that the addition of vitamin C to susceptible milk would prevent the occurrence of tallowy or oxidized flavor. When oxidized flavor had occurred naturally in milk, the vitamin C was greatly reduced.

In 1937, Brown et al. (44) found that pure crystalline ascorbic acid fed to cows at the rate of $\frac{1}{2}$ gram daily greatly decreased the tendency for oxidized flavor to develop in the milk. From the results of the experiments, it appeared reasonable to conclude that vitamin C in the rations of dairy cows may reduce or entirely eliminate the susceptibility of their milks toward the development of oxidized flavor.

When the oxidized flavor occurred, the vitamin C content was diminished, as reported by Dahle and Palmer (71), in 1937. The heating of the milk to 145° F. for 30 minutes caused little reduction of the vitamin C content, and heating the milk to 170° to 180° F. caused still less reduction. It was concluded that the factor responsible for the development of oxidized flavor was not necessarily responsible for the reduction of the vitamin C content of the milk.

Hand et al. (137) found, in 1938, that the addition of 0.005 to 0.01 percent of ascorbic acid delayed the development of the oxidized flavor in the milk.

Guthrie et al. (131) reported, in 1938, that, in general, there was a relationship between the factors which accelerate the rate of oxidation of ascorbic acid and the production of the oxidized flavor.

Samples taken throughout the year of commercial Grade A raw, irradiated pasteurized, and regular pasteurized milk were titrated for ascorbic acid content and on the third day were examined for development of oxidized flavor by Trout and Gjessing (299), in 1939. The samples of stored irradiated milk had a strong oxidized flavor, from late fall to early spring during the experimental year. The samples of Grade A raw milk had a less pronounced oxidized flavor during this period, but the off-flavor was still troublesome. No oxidized flavor was noted in the regular pasteurized milk throughout the year. The average first day values of ascorbic acid in the Grade A milk studied were 6.0, 10.5, 8.8, and 7.7 milligrams per liter during winter, spring, summer, and fall, respectively; the average values for pasteurized irradiated milk were 7.2, 11.1, 14.2, and 10.9 milligrams per liter; and for regular pasteurized milk the averages were 9.9, 12.9, 13.0, and 13.0 milligrams per liter of milk.

In 1939, Brown et al. (45) reported that ascorbic acid fed to cows at the rate of 1 gram per day reduced considerably the tendency for metal-induced oxidized flavor to develop, although it did not materially increase the ascorbic acid content of the milk.

Beck et al. (36), in 1939, found no relation between the amount of vitamin C in the original milk or between the amount of vitamin C lost during 3 days storage, and the development of oxidized flavor.

Greenbank (121), in 1940, conducted experiments to determine whether the amounts of ascorbic acid necessary to inhibit oxidized flavor formation would fall within the range of values for the amount of this compound normally present in milk. The results indicated that the presence of ascorbic acid can prevent the production of oxidized flavor; however, the amounts required were greater than the probable normal variations in this constituent.

Weinstein et al. (315) found, in 1940, that the addition of 35 milligrams of ascorbic acid per liter of milk prevented the development of oxidized flavor in milk processed with stainless steel and well tinned equipment, whereas a high percentage of unfortified samples became oxidized during storage at 40° F. for 72 hours. Thirty-five milligrams of ascorbic acid did not prevent flavor development of samples with $\frac{1}{4}$ p.p.m. added copper; 50 milligrams of ascorbic acid did not prevent flavor development of samples with $\frac{1}{2}$ p.p.m. added copper. Fifty milligrams of ascorbic acid in milk with $\frac{1}{2}$ p.p.m. of added copper and 150 milligrams of ascorbic acid with 1 p.p.m. added copper prevented the oxidized flavor.

From experimental results in 1941, it appeared to Brown et al. (46) that ascorbic acid in milk played a minor role in the susceptibility of milk to metal-induced oxidized flavor.

Brown et al. (47) , in 1941, concluded that the level of the ascorbic acid in the milk might not be as great a factor in the production of milk with low susceptibility to oxidized flavor as was formerly believed. A decrease in the ascorbic acid content of milk did not produce a corresponding increase in intensity of metal-induced oxidized flavor.

In 1941, Garrett (99) reported that divalent manganese had no effect on the rate of deterioration of ascorbic acid in uncontaminated and copper-contaminated milk.

Hartman and Garrett (142), in 1942, recommended titration of plant samples of milk for ascorbic acid on 3 or 4 successive days to reveal any abnormal rate of oxidation. Such procedure might lead to the detection of a hidden source of copper contamination.

In 1942, Brown and Olson (42) determined that: Washed cream fortified with ascorbic acid (210 milligrams per liter) or with dehydroascorbic acid (40 to 200 milligrams per liter) and contaminated with copper developed a strong oxidized flavor. A 0.1 percent potassium iodide concentration prevented, in most cases, the development of oxidized flavor in washed cream contaminated with copper and containing 210 milligrams of ascorbic acid per liter. These authors (224) also found that washed cream from nonsusceptible milk developed an oxidized flavor when contaminated with copper and fortified with ascorbic acid. It was postulated

that ascorbic acid in milk was oxidized by copper ions giving hydrogen peroxide as a product; the hydrogen peroxide was then thought to oxidize the phospholipids of milk producing oxidized flavor. Thiamine, pyridoxine, riboflavin, and cysteine in the presence of copper did not cause the development of oxidized flavor in washed cream.

Leeder and Herreid (190), in 1942, found that partial evacuation and storage of milk under a 23" to 25" vacuum decreased the rate of ascorbic acid and oxygen loss, and resulted in only one instance of oxidized flavor. Less ascorbic acid was lost from vat-cooled than from surface-cooled milk. Oxidized flavor did not appear in vat-cooled milk but often appeared in surface-cooled milk when held 2 days. More ascorbic acid was lost, after 2 days storage, in surface-cooled milk than in vat-cooled milk. It was found that milk might exhibit an oxidized flavor even though some ascorbic acid remained after 2 days holding; on the other hand, the milk might show no oxidized flavor, yet contain but little ascorbic acid.

In 1943, Hartman and Garrett (143) determined that the two oxidative reactions that occur in milk, involving ascorbic acid and the development of oxidized flavor, are independent of each other. Ascorbic acid, however, was more easily oxidized than was the fatty substance involved in the development of oxidized flavor. Consequently, ascorbic acid was oxidized first and accordingly acted as an antioxidant in that its presence delayed the onset of the second reaction.

Epple and Horrall (87), in 1943, reported that milk pasteurized in a tinned copper container had less copper contamination than that pasteurized in a stainless steel tube with alloy fitting, the ascorbic acid oxidized at a slower rate, and no oxidized flavor developed. The loss of ascorbic acid due to pasteurization in stainless steel or glass was only slightly more than the loss in samples of the same milk held 24 hours without pasteurization.

The results of experimentation by Olson and Brown (225), in 1944, indicated that the development of oxidized flavor in milk was closely associated with the ionization of copper and its destruction of ascorbic acid. The authors stated that apparently anything which decreased the ionization of copper, would in turn retard the destruction of ascorbic acid and tend to retard oxidized flavor development. Citric acid and amino acids formed complex ions with copper thus removing copper ions and protecting the ascorbic acid.

Krukovsky and Guthrie (181), in 1945, stated that the ascorbic acid oxidation in milk during storage at low temperature was an essential link in the chain of reactions resulting in the development of the tallowy flavor. This reaction could be inhibited by the quick and complete photochemical or chemical oxidation of ascorbic acid to dehydroascorbic acid prior to pasteurization and storage. Partial oxidation of ascorbic acid stimulated development of the tallowy flavor. Tallowy flavor was not promoted by 0.1 p.p.m. copper in milk completely depleted of all vitamin C by quick oxidation of the ascorbic acid to dehydroascorbic acid and subsequent pasteurization. The reaction, however, producing tallowy flavor was again induced by adding ascorbic acid to this milk.

In 1946, Krukovsky and Guthrie (182) presented evidence to show that a promoter (an enzyme) of ascorbic acid oxidation by H_2O_2 might have been responsible for its quick conversion to dehydroascorbic acid, and that it was not the free H_2O_2 formed in the course of ascorbic acid oxidation which caused the breakdown of the lipid fraction of the milk, resulting in the development of the tallowy flavor. The reaction which produced the tallowy flavor was catalyzed by added copper in the presence of H_2O_2 providing the agent was added to milk completely depleted ot its total vitamin C content by a rapid oxidative method, or the amount of the agent added was in excess of that required to oxidize its ascorbic acid content.

In 1949, Guthrie and Krukovsky (132) found that milk from which the vitamin C had been oxidized completely by sunlight, with or without added copper, did not develop oxidized flavor in 7 days in either homogenized or unhomogenized samples. The addition of commercial vitamin C to milk from which the original vitamin C had been eliminated resulted in oxidized flavors like those produced in the samples from which the original vitamin C had been eliminated. When vitamin C in homogenized or unhomogenized milk was oxidized partially by sunlight, with or without added copper, the sample of milk quickly developed a "very oxidized" flavor. The development of oxidized flavors as affected by the different factors studied was the same whether the milk was pasteurized before or after homogenization.

In 1951, Forster and Sommer (92) reported that although the addition of ascorbic acid to washed cream induced development of an oxidized flavor, a similar addition to susceptible milk would retard or prevent the flavor development. They presented two possible explanations: (1) Assuming that ascorbic acid acts as a hydrogen carrier, the excess amount added to the milk may simply be acting as an antioxidant; or (2) the ascorbic acid might react with some constituent of the milk serum, being oxidized itself while the other constituent is reduced.

Acidity

In 1937, Anderson et al. (5) reported that observations concerning oxidized flavor in pasteurized milk in a commercial plant indicated that the defect might be associated with the apparent acidity of the milk. The neutralizing of high-acid milk to 0.145-percent acidity or lower was effective in the prevention of oxidized flavor in pasteurized milk. Neutralization to 0.15-percent acidity did not prevent the development of oxidized flavor in all cases. Milk of high apparent acidity invariably developed an oxidized flavor upon pasteurization. The senior author (3) reported additional information in 1937. It was found that raw milk with high apparent acidity (0.19 percent) did not develop oxidized flavor in a 72-hour period. Pasteurized samples in four out of seven trials developed the off-flavor in 72 hours. At intervals the milk was neutralized to below 0.15-percent acidity. None of these samples developed oxidized flavor in 48 hours. Only in two out of seven trials did some samples of milk develop an oxidized flavor in 72 hours.

Brown and Dustman (39) reported, in 1939, that there did not appear to be any relationship between the acidity of freshly drawn milk and the intensity of metal-developed oxidized flavor. Standardization of the acidity of fresh milk to 0.13 percent did not prevent the development of the oxidized flavor when copper was added after pasteurization.

Lecithin, Lipids

In 1930, Davies (75) reported that the lipids were more active chemically than the fats and were likely to suffer oxidation first.

Thurston et al. (288) found, in 1935, that lecithin, rather than butterfat, appeared to be the constituent of milk affected when oxidized flavor developed. It was found that butter oil, free or practically free of lecithin, prepared by washing butterfat, became tallowy when oxygen was bubbled through it. Milk oxidized by the addition of ferrous chloride and low-temperature storage had a distinctly different oily-stale flavor. The results indicated, according to the authors, that the so-called oxidized flavor was not identical with the tallowy flavor of oxidized butterfat.

In 1935, Chilson (54) reported that the oxidized flavor of whole milk, commonly known as "cappy," "paper," or "cardboardy," appeared to be caused by an oxidation of the lecithin or similar substances absorbed on the fat globule rather than the oxidation of the true fat. He stated that the flavor known as "tallowy" was probably due to an oxidation of the oleic acid of the true fat.

Dahle (66) reported, in 1936, that the fat globule membrane, phospholipids, is susceptible to oxidation and might react before the fat itself. Dahle and Palmer (71), in 1937, reported additional work and concluded that the spontaneous oxidized flavor in milk is due to the oxidation of the phospholipids fraction of the fat globule membrane (lecithin) and the butterfat.

Roland and Trebler (258), in 1937, found that the mechanical separation of milk produced a marked decrease in its sensitivity to copper-induced oxidized flavor as shown by tests on milk made by recombining cream and skim milk. Removal of lecithin or related substances by the separation or changes in their distribution between the fat and the aqueous phase might have been responsible for the decreased sensitivity.

Dahle (67) stated, in 1937, that the fractions of milk which are responsible for off-flavor are the lecithin of the fat globule membrane which undergoes oxidation first and then the milk fat itself.

Josephson and Doan (168), in 1939, concluded from their studies that the phospholipid of milk was the substance responsible for the tallowy flavor, but that the protein of the fat globule membrane played a part in the reaction causing the flavor development.

In 1939, Beck et al. (36) found no relation between the frequency of occurrence of oxidized flavor and the lecithin content of the milk.

Swanson and Sommer (276), in 1940, concluded that the development of oxidized flavor in milk, catalyzed by copper was primarily due to the oxidation of the phospholipid fraction.

Gould et al. (118), in 1940, reported the results of analyzing 198 samples of milk for lecithin content. They found that feeds did not influence the lecithin content and that there was no relationship observed between the susceptibility of milk to copper-induced oxidized flavor and the lecithin content.

In 1951, Holm (159) stated that the lipids were involved in a greater number of types of spoilage than was any other class of milk constituents.

Fat

In 1937, Roland and Trebler (258) reported that the sensitivity of standardized milk and cream to copper-induced oxidized flavor appeared to be definitely related to the composition of the products as determined by the fat content. A variation of 1 percent fat in the range of whole milk was detected by a significant change in the flavor score.

Roland et al. (257) found, in 1937, that the fat content of milk having oxidized flavor was generally higher than the fat content of milks free from the defect. Milks of premium grade, generally high fat content and low bacterial count, were found to have oxidized flavor much more frequently than did the standard grade of milk, generally low fat content and high bacterial count.

Beck et al. (36) reported, in 1939, that there appeared to be a relationship between color intensity of the milk fat as produced by different breeds of cows and the development of oxidized flavor. Oxidized flavor was more prevalent in milks that were below breed average in fat color intensity.

Corbett (58) stated, in 1942, that oxidized flavor could be developed in milk in which the fat globule membrane had been removed, proving that oxidized flavor can result from oxidation of the butterfat.

In 1943, Corbett and Tracy (59) found that there appeared to be no correlation between the development of oxidized flavor and weekly milk or butterfat yield.

Krukovsky et al. (185), in 1949, reported that a significant correlation was found between the tocopherol content of milk fat and the ability of milk to resist the reaction which produces oxidized flavors.

Enzyme

In 1917, Thatcher and Dahlberg (282) reported that no oxidase was found in milk or butter.

Kende (176), in 1931, stated that oiliness of whole milk was caused by an oxidizing enzyme contained in the milk. The appearance or absence of the oily taste, its intensity, and the moment when the defect appeared or disappeared was found to be caused by an interaction of the following factors: Interior and exterior metal contamination; oleinase content; and reductases.

In 1935, Dahle (68) found that milk from certain cows developed an oxidized flavor in 48 to 60 hours at 40° F. The heating of the milk to 145° for 30 minutes intensified the flavor; heating to 175°F. eliminated the oxidized flavor. He stated that these facts pointed to the presence of an oxidase enzyme as the cause.

Chilson (54), in 1935, reported that an oxidizing enzyme was present in the skim milk which acted on the fat phase of the milk to produce the oxidized flavor. The enzyme appeared to be present in smaller quantities in summer than in winter. The oxidized flavor due to enzyme action was prevented by heating the milk to 170° F. for 10 minutes. The flavor did not develop in 4-percent-reconstituted milk from skim milk heated at 170° F. for 10 minutes and in unheated cream, but the flavor did develop in unheated skim milk and in cream heated at 170° F. for 10 minutes.

In 1936, Sharp et al. (269) stated that the effect of high temperatures of pasteurization in retarding the development of the oxidized flavor and the destruction of ascorbic acid could be explained by assuming the destruction of enzymes which if present accelerated these changes, and that the enzymes survived pasteurization at 145° F. The acceleration effect of soluble copper on the development of oxidized flavor and the oxidation of ascorbic acid was much more pronounced in the presence of the active enzyme.

Dahle and Palmer (71), in 1937, found that an enzymelike factor responsible for the oxidized off-flavor was carried in the plasma and serum of the milk.

In 1940, Tomlinson (290) reported that no evidence could be found to confirm the theory that the development of oxidized flavor was due to an enzyme. The main evidence in support of the enzyme theory was the inhibition by heat treatment. Data indicated the effect of heat treatment might be the result of chemical changes in the albumin fraction of the milk.

In 1942, Brown and Olson (42) reported work which indicated that no enzyme was involved in the production of an oxidized flavor.

Carotene

Dahle (66), in 1936, stated that carotene did not have antioxidative properties.

Beck et al. (36) reported, in 1939, that the development of oxidized flavor in raw milk was effectively prevented by feeding as little as 206 milligrams of carotene per head daily to cows that had been consistently producing milk with this off-flavor.

In 1941, Brown et al. (41) reported that results of tests indicated that the amount of carotene in butterfat might not be the substance responsible for the reduction in susceptibility of milk to oxidized flavor. It appeared that some substance or substances associated with it probably had a greater effect than did the carotene itself.

Albumin

In 1940, Tomlinson (290) stated that the addition of albumin before heat treatment (80° C. for 30 minutes) did not decrease the rate of oxidation of ascorbic

acid in milk after heating, although it did prevent the development of oxidized flavor.

Oxygen

Browne (48), in 1925, advanced the theory that the disintegration of the fats of milk was primarily caused by the action of nascent oxygen, one atom of which was liberated for each atom of oxygen absorbed at the points of unsaturation.

In 1931, Guthrie et al. (133) reported that aeration during pasteurization increased the tendency for the development of oxidized flavors.

In 1937, Dahle and Palmer (71) reported that the removal of the oxygen of susceptible milk by replacement with nitrogen prevented the off-flavor and reduced the destruction of vitamin C.

Guthrie et al. (131) stated, in 1938, that the destruction of ascorbic acid and the development of oxidized flavor in milk were largely or completely prevented by removal of dissolved oxygen.

In 1938, Hand et al. (137) determined that, by utilizing water vapor generated in the milk by vacuum distillation to sweep out the oxygen and preventing re-absorption, flavor defects due to oxidation can be avoided.

Leeder and Herreid (189), in 1940, stated that the evacuation and storage under partial vacuum diminished the oxygen content of the milk and tended to reduce the development of oxidized flavors.

Sharp et al. (266), in 1940, reported results indicating that market milk could be deaerated cheaply and easily by a continuous process. Deaerated milk had a greatly increased resistance to the development of oxidized flavor and the ascorbic acid remains stable. These authors (267) reported additional information in 1940. They found that as the temperature was raised oxygen was eliminated and that when milk was agitated at the lower temperatures, oxygen was absorbed. A correlation existed between high oxygen content of the milk and the intensity of the oxidized flavors. It was shown that deaerated samples of milk did not develop oxidized flavor and that check samples did.

In 1942, Sharp et al. (268) stated that little difficulty with oxidized flavor and the oxidation of ascorbic acid should be expected if the oxygen content of the milk were kept below about 0.4 to 0.5 milligram per liter.

Guthrie (126), in 1946, reported the oxygen content of milk might vary from zero or near that point, in the udder, to about 11 milligrams per liter, in the bottle, of undeaerated milk. An intermittent deaeration was used in a series of experiments. Flavor, after 7 days of storage, was "good" for the deaerated milk but was "poor" for undeaerated milk because of oxidized flavor.

Processing Factors

Homogenization

In 1933, Tracy, et al. (295) stated that the effect of homogenization in reducing tallowiness might be due to a difference in the taste reaction rather than to any reduction in the intensity of the oxidation of the butterfat.

Thurston et al. (287), in 1936, reported that homogenization at pressures as low as 500 pounds either reduced the intensity of the oxidized flavor resulting after the addition of copper or prevented the off-flavor altogether. At a pressure of 3,000 pounds there was no case of oxidized flavor. Homogenization, prolonged agitation at low temperature, and freezing and thawing (frozen at 0° F. stored 24 hours, thawed at 70° F.) of milk reduced or eliminated its susceptibility to oxidized flavor development.

Dahle (67), in 1937, reported that homogenization at a pressure of 2,000 pounds prevented oxidized flavor in the milk.

In 1937, Ross (259) stated that oxidized flavor in milk was prevented by proper homogenization pressures. Homogenization pressures of 500 and 1,000 pounds were partially effective; and a pressure of 1,500 pounds prevented the flavor with only two exceptions. Homogenization prevented the development of oxidized flavor in milk when copper was added to the milk after homogenization.

Doan (80), in 1938, reported that homogenization would definitely delay or even prevent tallowy or oxidized flavor in market milk. One exception is that homogenized milk is more sensitive to tallowy flavor induced by sunlight than is unhomogenized milk.

In 1940, Gould (112) showed that milk heated to 180° F. and then treated with small quantities of copper salts would lose its cooked flavor and become oxidized. However, if the milk were homogenized, either before or after the addition of the copper, the oxidation was prevented.

Larsen et al. (187) , in 1941, stated that homogenization of milk tended to stabilize the milk against oxidation, but that homogenization had no influence on changes in the oxidation-reduction potentials.

Babcock (27), in 1942, reported that homogenization retarded or inhibited the development of copper-induced oxidized flavor in milk. This was true when the copper contamination occurred either before or after homogenization. The degree to which homogenization would inhibit or retard the development of an oxidized flavor in copper-contaminated milk and the susceptibility of homogenized milk to copper-induced oxidized flavor, depended on the susceptibility of the milk before homogenization. It required the addition of approximately ten times as much copper to produce an oxidized flavor in homogenized milk as that required to produce a similar flavor in samples from the same supply of milk before homogenization.

In 1942, Corbett (58) stated that homogenization retarded the development of oxidized flavor by enveloping the fat globule in a protective casein membrane.

Guthrie and Krukovsky (132), in 1949, found that milk alone, or in the presence of copper, did not develop the oxidized flavors in 7 days when homogenized at pressures of 1,000 pounds or more. The development of oxidized flavors as affected by different factors in the study was the same whether pasteurized before or after homogenization.

Krukovsky (180), in 1952, explained the relative immunity of homogenized milk to oxidized flavors by the fact that in such milk the fat remained scattered and the unstable lipid component of the fat-globule membrane was split and withdrawn from the surface into the interior of the fat globules, where it was efficiently protected by the antioxidant activity of the fat.

Condensing

Corbett and Tracy (60), in 1940, found that condensing milk under vacuum to a concentration of approximately 2 to 1 was found to prevent the development of oxidized flavor in both the condensed milk and condensed milk reconstituted to the original solids concentration. Four-percent fat milk made from condensed skim milk and 32-percent cream did not develop an oxidized flavor even when 3 p.p.m. of copper was added. The authors thought that the effect of condensing in retarding oxidized flavor development was due to the liberation in the serum portion of the milk of certain antioxidative constituents that were probably derivatives of the milk protein.

In 1943, Russell and Dahle (263) reported that concentrated milk, either condensed or dried, acted as an antioxidant when added to fluid milk. High temperature treatments improved the antioxidant properties of concentrated milk. High temperatures after condensing, such as superheating, were more effective than similar temperatures applied to fluid milk in forewarming. Condensed whole milk was found to have much greater antioxidant effect than concentrated milk. Concentrated milk added to samples of raw fluid milk before pasteurization had greater influence than when added to samples from the same supply of milk after pasteurization and cooling.

Heating, Pasteurization

In 1933, Guthrie and Brueckner (130) reported that pasteurization temperatures of 160° F. and higher for 30 minutes apparently decreased or even prevented the tendency for the development of the oxidized flavors.

Dahle and Palmer (71), in 1937, found that pasteurization temperatures of 140° F. for 30 minutes and 160° F. for 5 minutes enhanced the degree of the oxidized flavor which might develop. Heating the milk to a temperature of 168° F. prevented the oxidized flavor.

In 1939, Gould and Sommer (119) stated that the sulphides liberated when milk was heated at temperatures of 80° C. or above explained the heat retardation and prevention of the oxidized flavor.

Gould, (111), in 1939, stated that if copper were added to milk and the milk heated to 84° to 86° C., or above, no oxidized flavor would develop. If heated to a lower temperature, the oxidized flavor would develop. If

heated to as high as 90° C. and then copper were added, oxidized flavor would develop. Heating milk momentarily to 80° to 82° C., or above, prevented the development of an oxidized flavor as induced by 2.8 p.p.m. of ferrous iron. This occurred irrespective of whether the iron was added before or after the heat treatment. The appearance of a strong cooked flavor at the temperatures used was correlated with the failure of the oxidized flavor to develop. The liberation of sulphides was related to the cooked flavor and prevented the development of the oxidized flavor.

Josephson and Doan (168) reported, in 1939, that the sulphydryl compounds were active antioxidants and appeared to be responsible for the inhibition of the development of tallowy or oxidized flavor in milk heated to temperatures above 170° F.

The pasteurization processes increased the frequency of oxidized flavors according to MacCurdy and Trout (198), in 1940. These authors (197) also reported, in 1940, that unaerated and aerated holder pasteurization resulted in a greater frequency of oxidized flavors in the stored milk than did vacuum pasteurization.

Greenbank (121), in 1940, stated that there was no indication from his data that heating increased the susceptibility to flavor formation. Heating raw susceptible milk to 158° F. for 10 minutes had been shown to decrease the Eh value and inhibit oxidized flavor development. However, if sufficient copper were added to a heated sample, it would develop the flavor.

Brown and Olson (42), in 1942, reported that pasteurization of milk at 180° F. for 5 minutes prior to washing of the cream did not affect the susceptibility of the cream to oxidized flavor when contaminated with copper. This revealed that the sulphydryls were contained in the plasma part of the milk and were removed sufficiently when cream was washed so as to render the cream susceptible to the development of the oxidized flavor with ascorbic acid. This indicated that no enzyme was involved in the production of an oxidized flavor.

In 1942, Corbett (58) stated that high heat treatment retarded the development of oxidized flavor by enveloping the fat globule in a protective casein membrane.

Nelson (220), in 1943, concluded that his study demonstrated that high-grade raw milk developed an oxidized flavor after pasteurization and that the oxidized flavor intensified with the age of the pasteurized milk.

Cooling, Storage

Davies (74), in 1933, stated that length and temperature of storage were important in the development of oxidized-fat flavor. Lower temperatures lowered the oxygen demand of micro-organisms. Long storage offered more opportunity for the taint to develop.

In 1936, Brown et al. (43) found that the exposure of milk to the air while being passed over a surface cooler did not cause any greater development of oxidized flavor than did the passage of milk through an internal cooler.

MacCurdy and Trout (198) reported, in 1940, that the storage of milk at 40° F. for 3 days increased the frequency of oxidized flavors in pasteurized milk.

Greenbank (121), in 1940, stated that oxidized flavor developed more rapidly and to a greater intensity in milk stored at 1.4° F. than in milk stored at 19.4° F.

In 1942, Corbett (58) found that the development of oxidized flavor could be prevented by storing milk under several atmospheres of carbon dioxide. Storing milk under atmospheres of nitrogen hastened the development of oxidized flavor.

Bacteria

In 1927, Mattick (211) reported that bacteria acted as a retarder in the development of oiliness in milk by absorbing oxygen or by producing acid or both.

Davies (74) found, in 1933, that a higher copper content would be necessary to give a taint (oxidized) in milk of high bacterial count, and that such a count might prevent the taint.

Tracy et al. (295), in 1933, reported that bacteria had the power to retard the development of tallowy flavor. Cream stored at 40° F. (2.6 p.p.m. copper added) became tallowy, but at 2 days storage at 70° F. no tallowy flavor was discernible. Good quality (low bacteria) milk was more likely to become tallowy.

Roland et al. (257), in 1937, reported that bacterial counts on milk of oxidized flavor were generally lower than counts on milk free from this defect.

Incubation of milk at 98° F. for 4 hours and addition of starter culture delayed or prevented the development of oxidized flavor, as reported by Dahle (67), in 1937.

Webb and Hileman (309), in 1937, stated that the decreased susceptibility of summer milk to oxidized flavor development did not appear to be due to bacteria.

Leeder and Herreid (189) stated, in 1940, that the growth of bacteria in milk held at atmospheric pressure diminished the oxygen content and tended to reduce the development of oxidized flavor.

Greenbank (121), in 1940, reported results on samples of raw milk held 48 hours at temperatures ranging from 41° to 68° F. At the end of the storage period, the sample held at 68° F. had a bacterial count of 109,000,000 and no oxidized flavor; the sample held at 41° F. had a bacterial count of 5,800 and a strong oxidized flavor.

In 1943, Cone and Babcock (57) inoculated freshly pasteurized milk that was susceptibile to the development of oxidized flavor, either spontaneously or with the addition of not more than 0.1 p.p.m. of copper, with nine cultures of oxidase-producing gram-negative bacteria. The inoculations varied from less than 100 to several million organisms per milliter of inoculated milk. The

milk was stored at 40° to 60° C. for 4 days. No inoculated sample developed a greater intensity of oxidized flavor than that of the uninoculated control. When large inoculations were used the oxidized flavor was markedly or completely inhibited. It was concluded that evidence was completely lacking to prove that the oxidase-producing bacteria differed greatly with respect to oxidized flavor in milk from other bacteria commonly found in milk.

In 1949, it was reported (14) that a certain type of bacteria, not common to udders, had been isolated from cows whose milk had an oxidized flavor. When pure cultures of the bacteria were inoculated into milk that was normally free of oxidized flavor, there was no flavor development. When the pure cultures were inoculated into susceptibile milk, the developed oxidized flavor became more intense.

Sterilization

Dahlberg and Carpenter (65), in 1936, reported that the development of oxidized flavor was most pronounced when chlorine sterilization was employed.

Antioxidants

In 1933, Tracy et al. (295) reported that live yeast cells were very effective in retarding fat oxidation.

Greenbank and Holm (123), in 1934, reported that of the phenols, only the ortho and para types are active as antioxidants for fats and oils. Hydroquinone and catechol were antioxidants, but resorcinol was not. Maleic acid (an unsaturated polybasic aliphatic acid) was also found to be an antioxidant for fats and oils.

Dahle (66), in 1936, stated that carotene did not have antioxidative properties.

Dahle and Palmer (71) reported, in 1937, that maleic acid added to susceptible skim milk did not prevent the development of oxidized flavor, but that the addition of vitamin C, hydroquinone, and oat flour prevented it. Carotene added to pure butterfat was ineffective when this mixture was emulsified with susceptible skim milk.

In 1937, Dahle (67) reported that the addition of 0.2 percent of oat flour to milk prevented oxidized flavor.

Dahle and Josephson (70), in 1939, concluded from experiments that it was apparent that paper milk bottles made from paper board which had been sized with oat flour before paraffining aided in preventing or delaying the oxidized flavor in market milk.

Josephson and Doan (168) and Gould (111) recognized, in 1939, that the sulphydryl compounds formed on heating milk were active antioxidants and inhibitors of the development of the oxidized flavor in milk.

In 1939, Anderson (4) reported that since he found, in 1937, that the addition of small amounts of pancreatic enzyme to milk prevented the development of oxidized flavor, 14 milk dealers in 4 States had found pancreatic extract effective as an antioxidant

Garrett (101), in 1940, reported that oat flour exhibited definite antioxidative properties in retarding the development of oxidized flavor in milk induced by contamination with copper or exposure to sunlight.

Nelson and Dahle (218), in 1940, found that oat flour inhibited copper-induced flavor even after ascorbic acid, which it did not protect, had disappeared. Citric acid failed to exhibit antioxidative properties when added to milk. The addition of very small amounts of trypsin and steapsin preparations to milk was found to inhibit the development of copper-induced flavor. Pepsin exhibited no antioxygenic properties. Crude sugar and gum guaiac exhibited antioxygenic properties. Gum guaiac was used in much smaller quantities than any of the other antioxidants. The authors believed that the beneficial effect of trypsin and steapsin was due to their action on the fatty material rather than to their action on the protein fraction of the milk or on the oxidation-reduction potential.

Greenbank (121), in 1940, reported that hydroquinone proved to be an effective antioxidant in preventing the development of oxidized flavor in milk. Two parts of hydroquinone were required to counteract the action of one part of copper.

In 1940, Doan and Miller (81) concluded that the proteolytic enzyme trypsin in excess of 0.00128 percent was effective as an antioxidant in the presence of 2 p.p.m. of added copper sulphate. Bitter flavor and coagulation of the milk on bottling became noticeable when the amount of trypsin used exceeded 0.0064 percent. The authors stated that the antioxygenic effect of trypsin in milk apparently was not explained by the hypothesis that sulphydryl compounds were produced by the action of the proteins, since no nitroprusside reaction was obtainable and since there was no measurable stabilizing effect on reduced ascorbic acid.

Josephson and Dahle (167), in 1941, reported that, when 0.02 percent of a concentrated extract of white maize flour was added to milk which was subsequently contaminated with copper, a definite antioxygenic effect was noted.

Garrett (99), in 1941, reported that divalent manganese added to milk contaminated with copper or iron completely inhibited or greatly retarded the oxidized flavor. Metallic manganese exhibited a similar effect. Aluminum did not prevent the oxidized flavor in copper-contaminated milk.

Corbett (58), in 1942, reported that the addition of certain antioxidants to milk retarded or entirely prevented the development of oxidized flavor. The most effective antioxidants were hydroquinone, tyrosine or soluble esters of tyrosine, and a pancreatic extract. Other less effective antioxidants reported were ascorbic acid, extract of cereal grains, and certain amino acids.

Brown and Olson (42), in 1942, found that susceptible milk contaminated with copper and containing 0.01-percent potassium iodide did not develop an oxidized flavor. Less concentrations of potassium iodide were ineffective in most cases.

In 1943, Nelson (220) determined that raw milk treated with pancreatic enzyme just before pasteurization and then pasteurized showed the same oxidized flavor tendencies as untreated milk, except that the oxidized flavor developed more slowly and was less intense at the end of 56 hours at 38° F.

Olson and Brown (226), in 1944, presented a possible explanation of various inhibitors for oxidized flavor. They concluded that proteins, citrates, and amino acids inhibited the flavor by forming complex ions with copper, thus repressing its ionization. Tyrosine, divalent manganese, lactose, and glucose inhibited oxidized flavor by being oxidized by hydrogen peroxide, thus protecting the phospholipids of the milk according to the authors.

In 1948, Stull et al. (275) reported that 0.00125 to 0.0075 percent nordihydroguaiaretic acid would prevent the development of the oxidized flavor 5 days at 40° C. in whole milk containing 0.3 p.p.m. of added copper.

Chilson et al. (55), in 1950, found that the addition of propyl gallate to freshly pasteurized milk at the rate of 20 milligrams per liter was found to prevent the development of oxidized flavor effectively for a 14-day storage period at 35° F. It was equally effective with or without 0.5 p.p.m. of added copper in the milk. Ascorbic acid, natural or added, was not stabilized by the propyl gallate.

In 1951, Forster and Sommer (92) stated that any treatment of milk which tended to cause protein hydrolysis or denaturation would expose more SH groups for the oxidation of protein. This, in turn, would tend to retard or prevent lipid oxidation and, hence, oxidized flavor development. They found that manganese salt prevented the development of an oxidized flavor in spontaneous milk and in susceptible milk containing added copper sulphate. The addition of pure trypsin also retarded or prevented the flavor development in spontaneous or susceptible milk.

Mattick (211), in 1927, Davies (74), in 1933, Tracy et al. (295), in 1933, Dahle (67), in 1937, and Leeder and Herreid (189), in 1940, all reported that the growth of bacteria in milk retarded the development of oxidized flavor.

Krukovsky (180), in 1952, stated that his data indicated that the antioxidant activity of fat as determined by tocopherol content and extension of this activity to the body of milk by redistribution of fat, played an important part in the retardation or prevention of reactions which produce oxidized flavors.

Oxidation-Reduction Potential

In 1933, Tracy, et al. (295) stated that the oxidation-reduction potentials were related to fat oxidation.

Thurston (283), in 1937, reported that copper and iron invariably caused a rise in the oxidation-reduction potential and the development of oxidized flavors. Salts of tin and aluminum, when added to milk, caused a reduction in the oxidation-reduction potential and oxidized flavor did not develop.

Webb and Hileman (309), in 1937, stated that the development of oxidized flavors in milk by the addition of copper was due to, or accompanied by, an increase of the oxidation-reduction potential of the milk to a point sufficiently high to bring about a change in some milk constituent. Summer milk was able to

resist the development of oxidized flavors even in the presence of a high oxidation-reduction potential. It was stated that mixed milk from a large number of herds would rarely develop oxidized flavor unless it was contaminated with copper or some other agent that would raise the oxidation-reduction potential. There was no relationship between oxidized-flavor and oxidation-reduction potentials of the milk of individual cows. In such samples, the flavor could develop with a very low oxidation-reduction potential.

Gould and Sommer (119), in 1939, stated that the liberation of sulphides was responsible for the heat lowering of the oxidation-reduction potential of milk. The sulphides served to explain the heat retardation and prevention of the oxidized flavor.

In 1940, Swanson and Sommer (277) concluded from their studies on oxidation-reduction potentials in relation to the development of oxidized flavor that the Eh value of the medium did not appear to inhibit or accelerate the development of the off-flavor.

Greenbank (121), in 1940, stated that his study showed that samples of milk exhibiting a relatively great increase in Eh value after addition of copper were susceptible to oxidized flavor formation, and that those samples with slight or no increase in Eh value did not develop the flavor sufficiently to be detected by the sense of taste. He stated further that the susceptibility of a milk to flavor formation might be correlated with the ease with which its Eh value changes in the presence of copper salts. The Eh value was complicated by the poising action (the resistance of the milk to change in potential). If a sample of milk were well poised at a low Eh value, the oxidized flavor would not develop. If poorly poised, the sample increased in Eh with contamination and the minor constituent oxidized to give the oxidized flavor. Greenbank concluded that by raising or lowering the Eh value of samples of the same milk, it had been possible to promote or inhibit the development of the oxidized flavor.

Nelson and Dahle (218), in 1940, reported that the beneficial effect of trypsin and steapsin in retarding the oxidized flavor was due to their action on the fatty material rather than to their action on the protein fraction of the milk or on the oxidation-reduction potential.

Larsen et al. (187), in 1941, reported that the mechanism by which homogenization prevented or retarded oxidized flavor development appeared not to be associated with the oxidation-reduction potentials.

In 1941, Garrett (99) in reporting the inhibiting effect of divalent manganese on the development of oxidized flavor stated that the manganese had no effect on the magnitude of the oxidation-reduction potential or the rate of deterioration of ascorbic acid in uncontaminated and copper-contaminated milk.

Detection, Measuring and Control

In 1930, Greenbank and Holm (124) stated that the rate of reduction of methylene blue in a fat or oil when catalyzed by light might serve as a measure of the rate of reaction of the initial oxidative processes and might therefore be utilized to determine the relative susceptibilities of fats and oils to oxidation.

Briggs (38), in 1931, reported that the acid, iodine, and peroxide values remain practically unchanged during the induction period. The acid value lagged behind the absorption of oxygen, and the peroxide value was also unsuitable for ascertaining the degree of oxidation or autoxidation after the induction period.

In 1935, Dahle (68) stated that the active principle causing the oxidized off-flavor in milk was found in the milk plasma. He further stated that butterfat was affected as was indicated by the iodine number which decreased in proportion to the degree of flavor present.

Greenbank (122), in 1936, reported that experimental work on oxidized flavor showed: (1) That elimination of metallic contamination was the first step in preventing development of oxidized flavor in milk; (2) that aeration and pasteurization prevented development unless excessive amounts of copper were present; (3) that the introduction of green feed into the ration was not always a preventive; (4) that the flavor may develop in milk any time in the lactation period; and (5) that the flavor is the result of an oxidation of a minor constituent of the milk.

Martin (209), in 1937, recommended the following practices to minimize or eliminate oxidized flavors in milk: (1) Use milk normal in composition, especially in respect to carotene; (2) use milk of low apparent acidity; (3) use noncorrodible equipment; (4) protect the milk from sunlight; (5) avoid freezing the milk; and (6) shorten the storage period as much as possible.

In 1937, Brown et al. (40) reported that in 12 trials during the winter months of 2 successive years no measurable change in the iodine number of milk fat could be found as the result of the development of moderate or fairly pronounced oxidized flavor.

Swanson and Sommer (276), in 1940, determined the iodine numbers of the phospholipid fractions from normal and oxidized milk. The development of oxidized flavor was accompanied by a marked decrease in the iodine number of the phospholipid fraction. No significant difference was found between the iodine number determination on samples of butterfat from normal and oxidized milk.

In 1940, Nelson and Dahle (217) found that the iodine number of milk fat did not decrease with the early development of the oxidized flavor. They observed that milk fat usually had a peroxide number of zero when freshly isolated even from milk or cream having a strong oxidized flavor which was carried over into the fat. They also showed that the peroxide number and iodine number did not change materially until the color of the fat was affected.

Brown et al. (41) reported, in 1941, that in cow rations low in fat the change in iodine number of the butterfat did not appear to be correlated with the intensity of the oxidized flavor developed.

Dahle (69) stated, in 1941, that oxidized flavor could be prevented by rejection of the milk of the cows at fault, correcting feeding practices, homogenization of the milk, high heat treatment of the milk, elimination of copper in direct contact with the milk, and use of antioxidants.

Corbett and Tracy (61), in 1943, concluded that the seasonal nature of the occurrence of oxidized flavor could not be explained on the basis of changes in the iodine number of the milk fat.

In 1951, Dunkley (84) reported investigating a test involving the chemical estimation of oxidized flavor based on the formation of a red color when oxidized milk was acidified and heated with 2 - thiobarbituric acid. He stated that the results demonstrated that this test correlated closely with the numerical flavor scores of the milk samples having oxidized flavor of varied intensity.

General

Thurston (284), in 1935, after reviewing the literature and his own experience, classified the various names used for oxidized flavor as follows:

(a) Indicating papery taste	(b) Indicating oxidation of butterfat	(c) Indicating taste of metals
(1) Cappy	(1) Oily	(1) Metallic
(2) Papery	(2) Tallowy	(2) Metallic-oily
(3) Cardboard	(3) Oily-tallowy	
(4) Pulpy	(4) Oily-stale	

(d) Used by foreign investigators

(1) Oleoginous
(2) Emery
(3) Corundum
(4) Empryrumatic
(5) Loamy-astringent
(6) Oily-tallowy
(7) Oleoginous-tallow like

The author stated that the following factors were causes of oxidized flavors: (1) Iron and copper; (2) susceptibility (some milk more susceptible than other milk); and (3) light. To prevent the development of the oxidized flavor, he listed the following control measures: (1) Elimination of copper and iron contamination; (2) growth of micro-organisms; (3) homogenization; (4) high heat treatment; and (5) controlling the feed of the cows.

Thurston (285), in 1937, suggested the following classification: (1) Spontaneous milk--develops oxidized flavor without copper or iron contamination; (2) susceptible milk--does not develop oxidized flavor spontaneously but will develop it with copper or iron contamination; and (3) nonsusceptible milk--does not develop oxidized flavor even when copper or iron is added.

In 1937, Trout and Sharp (305) found that a temperature of 21° C. appeared to give least taste reaction for the oxidized flavor in milk. The flavor involved an associated odor as well as taste. An analysis of commercial scores and criticisms of market milk indicated that the slightly oxidized flavor was frequently associated with, and often mistaken for, the cooked flavor. At 35° C. the flavors of the milk appeared to blend so that the oxidized flavor showed less distinct characteristics.

Roland et al. (257), in 1937, reported on a flavor, fat content, and bacteriological quality study of 139 samples of commercial pasteurized milk from 19 dairies in 16 different cities during the winter, 1935-36. They found oxidized flavor to be the predominating off-flavor encountered and to be present in 11 percent of the samples.

Greenbank (121), in 1940, stated that the results of experiments appeared to indicate that oxidized flavor in milk was caused by minor constituent or constituents. This was supported by the fact that in a reducing environment, such as that caused by the mechanical removal of air, removal of oxygen by bacterial growth, or presence of antioxidants, the oxidized flavor did nor form readily. On the other hand, conditions favoring mild oxidation, such as low temperatures of storage, presence of certain action of diffused light in the presence of metals, action of small amounts of hydrogen peroxide, favor oxidized-flavor formation. The author using poising (resistance of the milk to change in potential) as a criterion and Thurston's (285) classification stated that spontaneous milk might be very poorly poised, susceptible milk poorly poised, and nonsusceptible milk well poised.

In 1951, Holm (159) stated that tallowiness was caused by the hydrolysis of glycerides; that oxidized flavors generally were ascribed to the oxidation of phospholipids. He further stated that the glycerides of milk fat contain varying amounts of unsaturated acids, principally oleic, which add oxygen spontaneously to form hydroperoxides and subsequent reactions of the peroxides with the fat.

Keeney and Doan (170, 171, 172), in 1951, in a series of studies on oxidized milk fat found that the vacuum distillation of oxidized milk fat yielded material with the characteristic flavor and odor of the oxidized fat. Carbonyl compounds were found to be significant contributors to the characteristic odor of oxidized fat. In the advanced stages of milk fat oxidation, these authors found it possible to isolate flavor fractions which were typical of the earliest stages in the oxidation. They stated that changes in the flavor during the oxidation were due to a blending of different flavor compounds.

In 1951, Weinstein (312) found that human milk which contained more ascorbic acid, less protein, and which had a lecithin content comparable to cow's milk did not develop an oxidized flavor even in the presence of 0.25 p.p.m. of added copper.

Krukovsky (180), in 1952, stated that in fresh milk the oxidized flavors, such as chalky and chalky-to-soapy-tallowy, had been demonstrated to be associated with the deterioration of milk plasma (skim milk) and metallic and metallic to fishy

flavors with the deterioration of the fat globule membrane and oxidation-sensitive fat, respectively. The author stated further that with the passage of time, flavors in whole milk containing ascorbic acid and 0.1 to 0.4 milligram of copper per liter, changed from metallic to soapy-tallowy, the soapy flavor being dominant. With further increases in copper content, from 0.5 milligram to 10 milligrams, the soapy-tallowy flavors were superseded by metallic-to-fishy flavors.

IV.- SUNLIGHT FLAVOR

The effect of sunlight on milk was noted as early as 1920, by Hammer and Cordes (135). They concluded that with sufficient exposure to sunlight a definitely tallowy flavor was produced in milk and cream, and with less exposure a distinct "off" flavor developed. Since 1920, the sunlight effect has been reported by some investigators to be a contributing factor in producing an "oxidized" flavor in milk; other investigators have continued to report the effect as an off-flavor closely associated with oxidized flavor but distinct from it.

Oxidized Flavor

In 1930, Whitehead (320) suggested that sunlight catalyzes an oxidation-reduction reaction in milk in which unsaturated fats were oxidized and methylene blue was reduced.

In 1931, Guthrie et al. (133) stated that oxidized and related off-flavors of milk were caused largely by copper, and that such reaction was accelerated by sunlight.

Whitehead (321), in 1931, stated that the oxidation of fat in whole milk under the influence of sunlight caused the development of a reducing potential.

Davies (76), in 1931, stated that copper, ultraviolet light, and strong sunlight shortened the induction period and caused oxidation in milk.

Davies (74), in 1933, listed sunlight as an oxygen-activating agent, and stated that it might help the slightly increased copper content of milk processed in a satisfactory plant to bring on the oxidized taint.

Dahle and Palmer (71), in 1937, stated that the exposure of susceptible milk to sunlight caused the oxidized off-flavor to occur.

Hand et al. (137), in 1938, reported that the oxidation of ascorbic acid and of fat in milk was sensitive to variations in dissolved oxygen as well as to dissolved copper and exposure to light.

In 1938, Guthrie et al. (131) stated that, in general, there was a relationship between the factors which accelerated the rate of oxidation of ascorbic acid and the production of the oxidized flavor in milk. These authors reported that sunlight caused the oxidation of ascorbic acid. Paper bottles were found to decrease markedly the effect of sunlight on the oxidation of ascorbic acid and on the production of off-flavors in milk.

Doan (80), in 1938, stated that homogenization would definitely delay or even prevent tallowy or oxidized flavor in market milk. He reported, however, that homogenized milk was more sensitive to tallowy flavor induced by sunlight. Green glass bottles, or green cellophane wrappers, were found to efficiently protect homogenized milk from exposure to sunlight.

In 1940, Garrett (101) reported that oat flour exhibited definite antioxidative properties in retarding the development of oxidized flavor in milk induced by contamination with copper or by exposure to sunlight. He also reported that oat flour impregnated in the paper from which milk containers were made had an inhibiting effect on the development of sunlight flavor in milk.

England and Wiedemer (86), in 1941, concluded that increasing the length of time milk was exposed to sunlight increased the intensity of the oxidized flavor. Midday, sunlight induced more intense oxidized flavors in milk in glass bottles than did morning or afternoon sunlight, and morning sunlight induced more intense oxidized flavors in milk in paper bottles than did midday and afternoon sunlight. The exposure of milk to sunlight at 70° F. resulted in increased oxidized flavor development over that in milk exposed at 40° F. Paper bottles offered more protection than glass. Paper bottles treated with oat flour offered only slightly better protection to the milk than did plain paper bottles. The milk used in the experiment had not been exposed to copper at any time.

Babcock (27), in 1942, reported that homogenized milk was much more susceptible to the action of sunlight than the corresponding unhomogenized milk. Homogenized milk required approximately half as long an exposure to sunlight as unhomogenized milk to produce a sunlight-induced oxidized flavor.

Sunlight Flavor

As previously stated, Hammer and Cordes (135), in 1920, reported a definite tallowy flavor in milk after sufficient sunlight exposure, and a distinct "off" flavor with less exposure. Abnormal flavors developing in dairy products as a result of exposure to sunlight were prevented in the liquid products by the use of brown glass bottles as containers. These authors found that light had a greater effect on low- than on high-fat milk. "Off" flavors were observed in some milk samples after exposures of 10 minutes, and tallowiness was observed with exposures as short as 45 minutes.

Frazier (94), in 1928, reported that a "cardboard" taste and "linseed-oil" odor developed in whole milk which had been exposed to diffused daylight for 8 or more hours at about freezing temperature. The off-flavor and odor developed more rapidly in pasteurized than in raw milk (presence of enzymes or bacteria unnecessary). The off-flavor and odor developed no more rapidly in milk from cows fed heavy rations of cottonseed or linseed cake than in milk from cows fed no oil feed.

Roadhouse (249), in 1930, found that sunlight caused a definite "cappy" or "cardboard-like" taste in milk when exposed in clear glass bottles for 45 minutes. In 10 minutes, a slight off-flavor had developed. When the milk was put in amber glass or paper bottles the sun had no effect on the flavor. Strong sun rays shining against clear glass bottles produced oxidized flavor in the milk.

In 1931, Tracy and Ruehe (296) reported that two kinds of flavor defects-- one a tallowiness and the other a burnt flavor-- might occur in milk exposed to sunlight.

Tracy (291), in 1931, stated that recent studies had shown sunlight to be closely associated with the development of a tallowy flavor in milk. Milk in colorless glass bottles left exposed to the direct rays of the sun for even 30 minutes was found to be tallowy. In diffused light, the defect developed somewhat slower. Exposure to sunlight resulted in a very noticeable burnt flavor which was associated with the milk serum rather than with the butterfat. It was found that the tallowy flavor occurred more commonly in winter than in summer and more rapidly in milk held at 40° than at 68° F.

Marquardt (204), in 1932, found that the development of off-flavors in milk exposed to direct sunlight was directly proportional to the intensity of the sunlight and period of exposure. Jersey, Holstein, and mixed milks, ranging from 3 to 5 percent in fat, either raw or pasteurized, were reported to act alike when exposed to sunlight.

In 1933, Tracy et al. (295) stated that sunlight flavor might be confused with tallowiness. In sunlight flavor, metallic salts were found not to be a factor.

Doan and Myers (82), in 1936, reported that when milk was exposed to sunlight in paper and clear glass bottles, off-flavors were detected first in the glass bottles. Paper bottles offered appreciable protection to skim milk, whole milk, and buttermilk against the action of sunlight in causing burnt flavors as compared with clear glass bottles, but the paper bottles were no protection to whole milk and cream, homogenized or unhomogenized, against tallowy flavor caused by sunlight. Blue-and green-colored paper bottles or blue and green cellophane wrappers on paper bottles retarded the development of tallowiness and burnt flavor in skim milk, whole milk, cream, and buttermilk. The degree of tallowy flavor, in milk and cream, produced by sunlight, appeared to be greater in paper than in clear glass bottles. Burnt and tallowy flavors appeared to be distinct changes. The burnt flavor predominated in the low-fat products and the tallowy flavor predominated in high-fat products. The authors stated that the burnt flavor apparently had its source in the casein-free and albumin-free serum of the milk. Homogenization was found to accelerate sunlight-induced tallowy flavor.

Tracy (292), in 1938, stated that when homogenized milk was exposed to sunlight it rapidly acquired a burnt taste. Regular milk also acquired the off-flavor but the reaction was not as fast as that in homogenized milk.

Josephson et al. (166), in 1946, reported that most milk subjected to sunlight for as little as $\frac{1}{2}$ hour developed the very unpleasant "sunlight" flavor.

In 1949, Keeney (169), stated that the burnt, sunlight flavor in milk was peculiar to milk exposed to solar radiation or comparable artificial light energy and was not otherwise encountered. It was further stated that tallowiness might also be produced on exposure to light. The type of developed flavors was found

to be influenced by age of milk, presence of pro-oxygenic substances, and length of exposure. It was concluded that a dialyzable substance was essential for normal sunlight flavor development and that this fact seemed to indicate that the "activated" flavor of excessively irradiated milk and the sunlight flavor are not formed in a similar manner.

In 1951, Weinstein and Trout (316, 317, 318), and Weinstein et al. (313, 314), in a series of articles on solar-activated flavor of homogenized milk concluded that: (1) The solar-activated flavor referred to as "sunshine," "burnt," "burnt feather," "burnt protein," "scorched," "cabbage," "mushroom," and/or "medicinal" (chemical or iodine) was one of the major problems encountered in the distribution of homogenized milk. (2) Approximately 30 percent of the milk from individual cows on pasture failed to develop a solar-activated flavor following pasteurization, homogenization, and 30- and 60-minute sun exposures; homogenized milk from all cows on dry feed was susceptible to solar activation; and there appeared to be no correlation between breed of cow, stage of lactation, and fat percentage and susceptibility to the off flavor. (3) The light-induced "burnt" flavor of homogenized milk appeared to be associated with the milk proteins, and was probably an oxidative process. (4) Addition of ascorbic acid did not prevent the development of the solar-activated flavor of homogenized milk; the off-flavor was prevented in homogenized milk exposed 60 minutes to solar radiation by the addition of 25 milligrams per liter of nordihydroguaiaretic acid alone or 75 milligrams per liter in combination with ascorbic acid; alpha tocopherol and hydroquinone did not offer complete protection against the off-flavor and high-temperature (176° F. for 5 minutes) heat treatment did not retard or prevent it; and hydrogen peroxide added prior to pasteurization and homogenization prevented a typical solar-activated flavor. (5) Deaerated milk exposed to solar radiation did not develop the solar-activated flavor; and incorporation of air and a 60-minute reexposure of the deaerated milk resulted in the typical solar-activated flavor. (6) Homogenization subsequent to exposure accentuates the off-flavor. (7) A minor protein fraction (isolated from major protein free skim milk) was found capable of being photosensitized to produce the typical solar-activated flavor of homogenized milk; and analyses of the minor protein fraction indicated it was composed of at least two components or complexes.

In 1952, Herreid et al. (148) reported that the ruby-colored bottle--followed by amber, paper, and clear glass bottles--proved to be the most protective against sunshine flavor development in milk. These authors, found that the feeding regime of the cows and the aging of the processed milk affected the development of the off-flavor in milk. The sunshine flavor was found to develop in the amber bottle in milk from barn-fed cows, but the flavor did not appear after 2 hours of sunlight exposure in milk from pastured cows. After a 10-minute sunshine exposure in clear bottles, milk from barn-fed cows had developed a pronounced sunshine flavor which gradually decreased until after 2 hours there was only a questionable off-flavor in the milk. The off-flavor developed in the paper bottle in milk exposed to sunlight immediately after it was pasteurized and homogenized, but when the milk was held for 1 day or longer at 45° ± 5° F. before exposure no sunshine flavor developed.

Crowe (63), in 1952, reported that homogenized milk was more sensitive to light than unhomogenized milk and that homogenized milk would develop a light-induced sunshine or activated flavor. He found that the light-induced sunshine flavor gave a slower taste reaction than the oxidized flavor but that the sunshine flavor had almost a medicinal flavor and a faint odor.

V.- METALS, METALLIC FLAVOR

Metallic contamination was shown under the heading "Oxidized Flavor," to play an important role, as a catalyst, in the development of the oxidized flavor in milk. Milk that has been in contact with certain metals may develop an astringent, puckery, metallic taste distinct from the oxidized flavor.

The degree of off-flavor imparted to milk by metals is dependent on the type of metal and its resistance to being dissolved or corroded by milk. In view of the importance of selecting insoluble, corrosion-resistant metals for dairy equipment, research involving the use of different metals is included in this review.

Metals

In 1923, Rice and Miscall (247) reported a series of experiments with copper. They found that the presence of air and oxygen increased enormously the amount of copper dissolved by milk, but that carbon dioxide had no influence on the amount dissolved. Copper corroded with an oxide surface was found to yield much more of the metal to milk than did a smooth bright copper. The amount of copper taken up by milk increased with the amount of copper surface exposed and with the time of exposure. The authors found that at 145° F. considerable more copper was dissolved than at room temperature or at boiling. Slightly sour milk dissolved but little more copper than did normal milk.

By inserting copper strips in milk for 30 minutes, Quam et al. (238), in 1928, found that the solubility of copper in milk increased with rise in temperature to a maximum at 85° to 90° C. after which the solubility decreased.

Hunziker (160), in 1928, reported the results of experiments in which metals were checked with acids (dilute organic and mineral), alkalies, calcium, and sodium brines, and successive steam heating and brine cooling. He rated, in order of preference, the metals in accordance with their resistance to the agents used and their effect on the quality of milk as follows: (1) Superascoloy, tin, nickel; (2) tinned copper (heavy tin), aluminum, aluminum manganese alloy, enduro, ascoloy (chromium-steel); (3) monel metal, nickel silver; and (4) tinned iron, copper, galvanized iron, iron zinc. Hunziker et al. (164) reported similar results in 1929 and added that, with minor exceptions, the corrosion was more intense in high-acid products than in the low-acid products and at high temperatures than at room temperature. However, they found that even in the sweet milk products, and at room temperature, corrosion was by no means absent.

Guthrie (127), in 1929, grouped metals according to the amount of corrosion and the effect on the flavor of milk as follows: (1) No effect--Allegheny metal, aluminum, glass enamel, nickel (when milk was cold), chromium-plated metals, and tin-plated metals; (2) slight effect on flavor--ascoloy, nickel, poorly plated chromium-plated or tin-plated metals, or metals on which these platings had worn thin: and (3) definite effect on flavor--ambrac, brass, bronze, copper, monel metal, nickel bronze, nickel silver, Waukesha metal, and poorly plated copper or copper alloys.

In 1929, Quam (236) reported the solubility of aluminum, tin, and 18-percent chromium steel at temperatures of 25° to 75° C. to be negligible. Nickel, zinc, and copper solubility progressively increased with temperature increases, with maximum solubility at 80°, 75°, and 90° C., respectively, after which the solubility decreased.

Miscall et al. (212), in 1929, reported that the copper-dissolving power of milk increased at temperatures up to 140° to 145° F. and then decreased. Either the removal of the milk gases or the addition of carbon dioxide decreased the copper-dissolving power of the milk. These authors found that the presence of oxygen increased the amount of copper which went into solution. Pasteurized milk dissolved more copper than raw milk at the same temperature.

In 1930, Sommer and Gebhardt (273) reported that, when milk was placed in a copper container, any agitation markedly increased the amount of copper dissolved. They found that size of area and length of time of exposure to copper directly influenced the amount of copper dissolved by milk. Ordinary pasteurization temperature increased the amount of copper dissolved by milk to five times that dissolved at room temperature. The amount dissolved increased as the temperature increased up to 160° F. Above 160° F., there was a marked progressive decrease until at boiling temperature only slightly more copper was dissolved than at room temperature. Bubbling carbon dioxide through the milk was found to cause marked reduction in the amount of copper dissolved.

Gebhardt and Sommer (107), in 1931, reported that higher acidities markedly decreased copper solubility in milk and that slight increases in acidity had no effect. When bubbled through the milk, carbon dioxide markedly decreased, air slightly increased, and oxygen markedly increased the copper solubility in the milk. Temperature greatly affected copper solubility (maximum at 70° C.). Solubility of copper in milk at boiling was the same as that at room temperature. Gebhardt and Sommer (108) reported that by residual-current measurements the amount of copper dissolving in milk could be calculated with fair approximation to the gravimetrically determined values.

In 1932, Fink and Rohrman (88) found that nickel corroded in milk more readily in the absence of oxygen. They found that high chromium-nickel iron alloys, chromium-plated copper, and chromium-plated nickel were very resistant to corrosion by milk and that these metals were satisfactory for dairy equipment on this account.

Trebler et al. (297), in 1932, reported that nickel was corroded only slightly in milk heated to pasteurizing temperature and held. Chromium nickel alloy and chromium-nickel iron alloy were resistant to corrosion in milk under all operating conditions.

In 1932, Gebhardt and Sommer (109) reported that the solution of Allegheny steel, stainless steel, aluminum, and tinned copper was very slight in acid milk at room temperature, and in fresh milk at various temperatures and oxygen contents.

Hileman (155), in 1933, stated that all metals in contact with milk dissolved but slowly at temperatures below 80° F. At higher temperatures, nickel was found to have the highest solubility rate of any of the metals commonly used in milk plants, but that nickel never appeared to cause bad flavors in the milk. The solution rate of tin was very low at all temperatures, and bronze was little more soluble than tin. The solution rate of copper and of nickel-copper alloys were between those of tin and nickel. The author warned that nickel-copper alloys might be just as detrimental to the quality of milk products as is pure copper itself, and that the alloys were more dangerous because they did not have the appearance of copper.

Gaul and Staud (106), in 1935, ascertained metallic contamination of dairy products by a spectrographic analysis. They stated that pasteurization increased the amount of copper, nickel, and tin in milk.

In 1940, Henderson and Roadhouse (144) studied copper-nickel alloys and reported that less copper went into solution from the alloys containing tin and zinc, so that the flavor of the milk was less influenced, than with alloys in which these elements were absent. They found the influence on ascorbic acid destruction by alloys rather than the rates of corrosion to be a more reliable index of their effect on milk flavor. Nickel, lead, and zinc did not influence the oxidation of ascorbic acid and did not cause oxidized flavor in the milks pasteurized in contact with pure strips of these metals.

Metallic Flavor

In 1916, Guthrie (128) reported that the direct absorption of metals could cause metallic flavor in dairy products.

Donauer (83), in 1922, stated that the amount of metals absorbed by milk could be great enough to produce a metallic flavor or aftertaste in the milk (metallic lactates had strong puckery tastes). He stated further that a considerable proportion of the vitamins in milk products might be destroyed by metals.

Hunziker (161), in 1923, found that all base metals so far applicable to dairy equipment construction were more or less soluble in lactic acid solutions and that their lactates had a bitter, puckery, astringent, metallic taste. He found the intensity of metallic flavor per unit of metallic lactate to be greatest in the case of copper and copper alloys (such as bronze, German silver, white metal). Equipment made of iron, copper, or copper alloys imparted a metallic flavor to milk products. He stated that tin and nickel appeared to be the only metals that produced no detrimental effect on the quality of milk products. Tin plating (heavy and complete cover) diminished the detrimental effect of other metals. Nickel plating peeled, and aluminum was found not suited for large equipment. Glass and enameled steel gave no metallic action.

Quam and Solomon (237), in 1927, placed 3" x 3" pieces of highly polished metals in 500-milliliter glass flasks, sterilized the flasks, and then added 400 milliliters of milk and stored the samples at room temperature. The samples were checked daily for odor and taste. The sample of milk containing a strip of magnesium had a bitter taste by the second day. The wrought iron sample had a pungent, sour odor and an acid, metallic taste. The sample containing a strip of copper developed early signs of putrefactive decomposition. Samples of milk exposed to nickel, chromium steel, tin, and properly tinned copper were not affected.

Hunziker (160), in 1928, stated that iron, galvanized iron, and tinned iron produced a very intense metallic putrid flavor in dairy products. Copper, copper alloys, and tinned-copper (properly tinned safe surface, but short life) were found to have a damaging effect on the quality of milk products by producing an intense oily, tallowy, and metallic off-flavor. Minute amounts of copper salts produced progressive flavor deterioration in dairy products with age (oxidative and catalytic changes).

Guthrie (129), in 1929, stated that many off-flavors, including the distinctly metallic flavors, could originate in the action of metals on milk. He further stated that copper was generally recognized as the leading offending element in the production of metallic flavors. He agitated various metals (aluminum, copper, chromium metals, nickel, nickel silver, tinned copper, and tinned plate) with milk at 70° to 80° F. for 1 to 5 hours, and at 142° to 144° F. for a total time of $1\frac{1}{2}$ hours. Tinned plate (not worn off) aluminum (Eng. and Amer.), and chromium metals (enduro steel, ascoloy) showed slight or no corrosion and did not impart a metallic or objectionable flavor.

Hunziker (164), in 1929, concluded that generally those metals that showed definite corrosion in milk also had the most damaging effect on the flavor of the milk product. He reported that iron, galvanized iron, and copper produced a marked metallic flavor in all milk products, and that zinc, tinned iron, and nickel silver produced such a flavor in the majority of cases.

In 1929, Guthrie (127) reported that Ambrac, brass, bronze, copper, monel metal, nickel bronze, nickel silver, Waukesha metal, and poorly plated copper or copper alloys produced a definite astringent, papery, metallic, or oily flavor in milk.

Ruehle (260), in 1930, reported that experiments indicated that metallic flavor could be imparted to milk and butter by the presence of iron or copper lactate.

Hunziker (162), in 1930, stated that common off-flavors of which metallic contamination might be a factor were metallic, bitter, puckery, sweetish, oily, cappy, and barny. The salts of highly soluble metals were reported as having a metallic taste and the property of inciting oxidative and catalytic action most likely to affect flavor.

In 1935, Burgwald (51) reported on the grading of raw and pasteurized samples of bottled milk. Of 136 bottles of milk graded in December 1934, 23 were criticized for tallowy or metallic flavor. Of 145 samples graded in February 1935, 27 were criticized for tallowy or metallic flavor.

VI.-COOKED FLAVOR

With the advent of pasteurization of milk, "cooked" was added as a possible flavor defect of bottled milk. This defect gave rise to some of the early discrimination against pasteurization, because the finished product did not have what many consumers called the "good raw milk flavor." At the present time, with flow-diversion valves, recording thermometers, and other refinements that make it possible to assure adequate pasteurization without overheating, the complaint of "cooked flavor" has practically disappeared. However, in some small towns there may be milk plants that do not have the latest equipment in controls and this flavor may still be a serious problem. It is important for plant operators to know temperature and time relationships that will enable them to produce a safe milk, without excessive "cooked" flavor. A slight cooked flavor apparently is not objectionable to most consumers who have become accustomed to it.

In 1916, Barthel (33) stated that the Swedish method of pasteurization employed by the dairy industry of that country was a continuous method employing a temperature of at least 176° F. for 1 to 1½ minutes. He further stated that milk pasteurized at 176° had a slight cooked flavor even when cooled immediately. He experimented with the American "holder" system of pasteurization and reported that milk pasteurized for 20 to 30 minutes at 145° had no cooked taste,but that the flavor became noticeable at 149° F.

Wright (328), in 1923, reported that the flavor and odor were usually cleaner in the case of milk pasteurized in a glass tank at 142° to 145° F. for 30 minutes. He stated that there was a slight heated taste in some of the milk when it was pasteurized in a glass tank, but that the off-flavor was not serious.

Hunziker (163), in 1925, stated that commercial experience in pasteurizing milk had shown that applying temperatures much above 145° F., for a sufficient length of time to accomplish maximum germ-killing, tended to impart a cooked flavor to milk. He found flash pasteurization at 185° F. wholly unsuitable.

Tracy and Ruehe (296), in 1931, reported that pasteurization improved the flavor of most raw milk. However, it was found that continued heating at 142° F. for more than 1 hour might result in a noticeable cooked flavor.

Yale (330), in 1934, stated that neither high-temperature nor low-temperature pasteurization, when the proper methods are employed, impart a heated flavor to the extent that it would be noticed by the average consumer. He reported that the average observer probably did not notice a heated flavor until the milk had been heated above 145° F. for 30 minutes or at 160° F. or above for periods of 2 minutes or more.

Marquardt and Dahlberg (206), in 1934, used heating water as high as 210° F. or steam at 220° F. under pressure to pasteurize milk in a glass-lined vat without imparting a cooked flavor. In a stainless steel-lined vat heating water of 200° F. was used without imparting a cooked flavor to the milk.

The design and size of the pasteurizer affected the rate of heat transfer and the temperature which could be used for the heating medium. Momentary heating to 170° F. for 1 minute did not produce a cooked flavor. These authors concluded that milk would withstand much more severe temperatures without developing cooked flavors than was generally supposed. Cooked flavors tended to leave during aging of the milk.

Tests made in 1938 (12) indicated that steam could be used as the heating medium with no detrimental results if sufficient agitation were employed to provide a rapid transfer of heat.

Gould (111), in 1939, differentiated between "heated" or "pasteurized" flavor, resulting from ordinary pasteurization procedures, and "cooked" flavor. He correlated hydrogen sulphide liberation in milk with the cooked flavor. The cooked flavor resulted after heat treatment at 84° to 86° C.

Josephson and Doan (168), in 1939, reported that cooked flavor became definitely evident in milk flash heated to 170° F., heated to 160° F. and held 15 minutes, and heated to 155° F. and held 30 minutes. These authors believed two or more sulphydryl substances might be involved in the production of the cooked flavor.

In 1939, Babcock (28) stated that consumers sometimes objected to pasteurized milk because of a cooked taste. He further stated that if a cooked taste occurred, it was due to overheating or to heating too rapidly. Properly pasteurized milk was reported to be equal to raw milk in flavor.

Gould and Sommer (119), in 1939, stated that the cooked flavor of milk was caused by the formation of sulphides which occurred when milk was subjected to sufficiently high temperatures or by changes occurring simultaneously with their formation. The cooked flavor was found to be pronounced at temperatures of 80° C. or above. When held 30 minutes at 70° C. one of five samples was graded "questionable" in regard to cooked flavor.

Gould (113) , in 1940, reported a close relationship between the temperatures at which the cooked flavor appeared in milk and those at which peroxidase was inactivated. Gould (112) reported that milk heated to 180° F. and then treated with small quantities of copper salts lost its cooked flavor and became oxidized. Milk to which was added 1.5 to 2 p.p.m. of copper and then homogenized showed practically no cooked flavor after 24 hours storage, and was of fine flavor even after 120 hours.

MacCurdy and Trout (198), in 1940, reported that the predominating off-flavor in day-old samples of milk pasteurized with and without aeration, at 143° F. for 30 minutes, was heated. Less heated flavors were noted in samples of milk flash pasteurized at 160° F. for 15 seconds than in the holder pasteurized samples.

Holland and Dahlberg (158), in 1940, stated that it was repeatedly observed that cooked flavors were much less pronounced in milk pasteurized for 2.5 seconds at 170° F. than in milk pasteurized at 143° F. for 30 minutes.

In 1941, Wolman (326) reported that temperatures of at least 150° F. or even higher for 30 minutes could be regularly employed without producing an undesirable heated taste to the milk.

Nelson (220), in 1943, found that pasteurized milk samples had a slight cooked flavor after 8 hours storage at 38° F.

In 1943, Spur (274) reported that homogenization of milk makes it possible to apply pasteurizing temperatures by the holding method up to 150° F. without any danger of developing a cooked flavor in commercial market milks. A slight indication was found that at 150°F. there was less danger of cooked flavor when pasteurization preceded homogenization.

Hankinson et al. (138), in 1946, reported that dialysis experiments on raw milk demonstrated that an unrecognized substance of low molecular weight could be removed which contributed to the flavor of heated milk. The dialysate from the raw milk when heated to 80° to 100° C. produced a heated milk flavor and odor. However, it was not the typical sulphide aroma obtained from heat-coagulated proteins. Some of the properties of the partially purified cooked flavor precursor were established, significant of which were its solubility in water, lesser solubility in methyl alcohol, and insolubility in acetone, ethers, and chloroform. There was no phosphorus or sulphur present in the compound. The authors concluded that the flavor and aroma of heated milk appeared to be derived from two sources, the heat coagulable proteins and a dialysate factor.

Patton and Josephson (231), in 1949, demonstrated that furfuryl alcohol was a compound generated in milk by heat and is not a normal constitutent of unheated milk. These authors (232) also found that the sulphydryl groups disappeared in skim milk heated for prolonged periods at high temperatures. The disappearance depended on a reaction involving lactose and casein and was correlated with the development of caramelized flavor and browning. They stated that the sulphydryl substances associate themselves physically and/or chemically with the casein in heated milk.

In 1952, Hutton and Patton (165) found the serum protein, B-lactoglobulin, to be responsible for the heat-induced cooked flavor in skim milk. They stated that conversion of -SH groups to H_2S as a result of heat treatment might explain, in a general way, the mechanism whereby B-lactoglobulin gives rise to cooked flavor.

VII.-RANCID FLAVOR

The rancid off-flavor in milk is now generally recognized to be due to the hydrolytic splitting of milk fat by the action of the enzyme, lipase. The liberation of fatty acids, especially butyric, imparts to milk the typical rancid flavor and odor. The stage of lactation, temperatures of handling and storing and processing procedures are among the factors that have been found to affect the activity of the normal milk enzyme, lipase, and consequently to affect the development of the rancid off-flavor.

In 1913, Echles and Shaw (85) observed that four cows near the end of their lactation periods produced milk that developed, within 24 hours after it was drawn, a strong abnormal taste and odor. They described the off-flavor as a rancid and bitter taste combined.

Palmer (229), in 1922, failed, after using several methods of analysis, to show that cow's milk normally contained active lipolytic ferment. The author (230), later in 1922, reported that bitter milk of advanced lactation was caused by the secretion of an active lipase in the milk which hydrolyzed the milk fat rapidly even at fairly low temperatures. The hydrolysis resulted in the liberation of fatty acids among which were the lower volatile fatty acids, especially butyric which imparted, in large measure, the bitter flavor and rancid odor to the milk. The off-flavor was stated not to be of bacterial origin and to be effectively retarded, if not prevented entirely, by heating the fresh milk to 75° C. for a few minutes.

Rice and Markley (246), in 1922, stated that milk normally contained a lipase which split butterfat. They further stated that the rancidity of fats and oils resulted from hydrolytic splitting as a result of lipase action. They found that the actual fat hydrolysis in milk resulted in liberation of free butyric acid and the development of the characteristic odor of that substance.

Rice (245), in 1926, reported that rancidity in condensed milk was caused by the accidental incorporation of raw milk into the batch. He stated that the activity of the raw milk was due to the presence of a natural lipolytic enzyme which split the milk fats and yielded among other fatty acids those of low molecular weight such as butyric. The rancid flavor was due to butyric acid.

Ramsey and Tracy (239), in 1933, reported that "cowy," "rancid," and "soapy" flavors in raw milk had been found to be due to a change in the butterfat and that the flavors were representative of different steps of the reaction. They stated that the increase in titratable acidity coincident with these flavor changes suggested a hydrolysis of the butterfat. The agent of hydrolysis was found to be inactivated by pasteurization and to be activated by homogenization.

In 1934, Anderson (9) concluded that normal milk contained small quantities of lipase. Milk which became bitter was found to contain abnormally large quantities of lipase. The cows that yielded bitter milk were in advanced stages of lactation.

Babcock (29), in 1934, reported an optimum homogenizing temperature (86° to 104° F.) for the development of a rancid flavor in raw homogenized milk. Raw milk homogenized within the temperature range of 86° to 104° F., although cooled and stored at a low temperature, became rancid within 18 hours after homogenization. At 40° to 50° F. homogenizing temperatures, the milk remained of good flavor for 18 hours but developed an abnormal flavor upon further aging. When homogenized at 59° to 131° F., a slight rancid flavor developed; at 68°, 77°, and 113° F., a rancid flavor developed at 18 hours but to a less degree than that for the milk homogenized at 86° to 104° F. The milk homogenized at 140° F. remained of normal flavor. The author also determined that cooling and storing the homogenized milk at a low temperature apparently retarded the development of the rancid flavor. However, the cooled samples showed the same degree of rancidity as the uncooled samples within 10 minutes after being warmed. It was found that varying the homogenizing pressure did not affect the development of the rancid flavor. The author concluded that homogenization couldn't be applied to raw milk for commercial purposes, and that in handling raw milk care must be used not to subject it to any process or agitation which might have an homogenizing effect, especially at temperatures within the optimum temperature range for causing a rancid flavor.

Hileman and Courtney (156), in 1935, reported that the increase in acidity with accompanying bitter flavor which occurred at certain seasons of the year in raw cream held at icebox temperatures was due to the activity of lipase. The lipase was found not to be of bacterial origin, but to be secreted by cows with the milk. These authors reported increasing amounts of lipase in the milk as the period of lactation was prolonged.

Anderson (7), in 1937, reported that he had been able to cause a change from the production of good milk to milk which acquired rancid flavors simply by changing the hay fed to the producing animals from good machine-dried alfalfa hay to poor field cured alfalfa hay.

Reder (240), in 1938, reported that milk from Jersey cows frequently producing rancid samples had a higher chloride and a lower lactose content than did normal milk produced in the same lactation period. The author (241) further reported that, in general, the rancid milk had a higher content of total solids, fat, and protein than did normal milk of the same lactation period. The increased protein content of rancid milk was attributed to an increase in the amounts of both the casein and lactalbumin fractions.

In 1938, Trout and Gould (300) stated that homogenization accelerated hydrolysis with resulting rancidity. They recommended pasteurizing the milk before or immediately after homogenization to inhibit the off-flavor development.

Reder (242), in 1938, reported that the production of rancid milk could not be explained on the basis of a change in the fatty acid content, cholesterol content, or lipolytic activity of the blood serum of the cows.

Doan (80), in 1938, reported that the critical preheating temperatures for inhibiting rancidity in homogenized milk had been found to be 148° F. flash, 137° F. for 15 minutes, and 132° F. for 30 minutes, applied either before or immediately after homogenization. It was found that in unpreheated milk, rancidity could usually be detected within 30 minutes following homogenization, especially when high pressures were used.

Krukovsky and Sharp (186), in 1938, reported that: Shaking of raw, whole cow's milk, while the fat was in the liquid state or partially liquefied state, induced lipolysis. Such lipolysis continued after the milk was cooled to low temperatures. The amount of lipolysis induced had little or no relation to breed, season, or milk production of the cow. If subjected to activating treatments, all milk was capable of lipolytic activity. Only milk from some cows, particularly those in advanced lactation in winter, would show natural lipolytic activity when cooled and held.

Keith (173), in 1939, reported on 5,000 flavor observations of the milk of individual cows. It was observed that 10 percent of the samples of milk indicated the presence of rancidity. In most instances, the flavor occurred when the cows were well advanced in lactation. The off-flavor was noted frequently in fall and infrequently during the summer. In most cases, the milk was free from the off-flavor when drawn. Milk that became rancid at 40° F. would not show any trace of the defect if stored at 70° F. for the same period. Storage of the milk at 0° to -10° F. for 15 hours was found to prevent the defect. Milk stored at 70° F. for 15 hours and then stored at 40° F. did not become rancid. Pasteurization of the milk at 145° F. for 30 min. within a few hours after it had been drawn definitely prevented the occurrence of the defect.

In 1939, Herrington and Krukovsky (150, 151, 152) in a series of articles on the lipase action in milk stated that it was generally recognized that cow's milk contained an enzyme capable of hydrolyzing fat. They further stated that this enzyme was responsible for the rapid development of rancidity in homogenized raw milk and the bitter flavor often associated with milk secreted by cows in a late stage of lactation. They found that lipolysis occurred in practically all samples of raw milk; that the rate of lipase action was influenced by the rate of cooling of the milk, being retarded by sufficiently rapid cooling; and that milk contained at least two lipases, one inhibited by very small amounts of formalin and the other not sensitive to moderate amounts of formaldehyde. They also found that lipolysis in cold milk was accelerated by warming the milk slightly and re-cooling (maximum activation--precool milk to 5° C. or lower, re-warm to 30° C. and re-cool below 10° C.) The rate of lipolysis appeared dependent on the crystalline state of the fat. It was found that milk which had been activated could be reactivated or deactivated by suitable heat treatments. These authors also reported that there was no apparent correlation between the rates of lipolysis and the stage of lactation, the stage of gestation, or the milk production of the individual cows.

Garrett et al. (105), in 1939, reported that the feeding of molasses grass silage appeared to retard the development of hydrolytic rancidity in milk.

Gould and Trout (120), in 1939, observed that when homogenized pasteurized milk was mixed with homogenized raw milk and the mixed milk was stored, the increases in acidity obtained were greater than the calculated values if only the raw milk underwent lipolysis.

Martin et al. (210), in 1940, found that storage of milk samples in partially filled bottles strongly favored the development of rancid flavors as compared with the development in full bottles.

Gould (114), in 1940, showed that raw milk heated momentarily and homogenized at 70°, 105°, 125°, 135°, and 145° F. underwent lipolysis in every case, the greatest lipolytic activity occurring in the temperature zone of 105° to 125° F., inclusive, and very little occurring at 70° and 145° F.

In 1941, Gould (115) reported that lipolysis in homogenized raw milk was not affected in all cases by the same factors (not inhibited by copper or formalin, lipolysis not accompanied by oxidation) which had been found to influence the rate of fat splitting in normal milk. He stated that whether these variations were due to different lipases or to physical or physico-chemical changes involving the fat globules had yet to be definitely determined.

Larsen et al. (188), in 1941, found that rancidity developed readily in mixtures of milk composed of (1) unhomogenized raw milk and homogenized pasteurized milk, (2) homogenized milk and homogenized pasteurized milk, and (3) unhomogenized raw milk and homogenized raw milk. These authors reported that the development of rancidity appeared to be equally dependent on the amount of lipase present and the amount of acceleration afforded by the newly created surfaces.

Trout and Scheid (304), in 1941, demonstrated that milk tempered 24 hours at 40° F. and then homogenized under 5,000 pounds pressure at 40°, 60°, 80°, 100°, 120°, and 140°F. developed rancidity at the 80°, 100°, and 120°F. exposures but not at exposures above or below those temperatures.

Krukovsky and Herrington (183), in 1942, reported the relationship between the judges' scores and the "acid degrees" (free acids in fat) of raw milk within a few hours after milking. The data indicated a threshold value for the recognition of rancidity at acid-degrees near 0.8. The data also indicated that very slight degrees of lipolysis might influence a judge's score without his being aware of the reason. Herrington and Krukovsky (153) reported that the rate of lipolysis in milk stored at low temperatures depended on the rate at which the milk was cooled before the storage period. To obtain a minimum of lipolysis, it was found that the cooling time should be reduced to a few seconds. These authors reported a criticial temperature range (0°C. natural milk, 10°C. temperature-activated milk, to 20° to 25°C. for both milks) in which the rate of cooling was most important.

Tarassuk (278), in 1942, stated that rancidity in milk could come about from two different sets of conditions, as follows: (1) Induced rancidity, resulting from faulty processing and leading to activation of one kind of lipase which appeared to be present in all raw supplies of milk; and (2) spontaneous rancidity, resulting from the presence of a naturally active lipase in high concentrations, occurring in milk of late lactation. He reported the causes of induced rancidity to be: (1) Prolonged and violent

agitation of warm milk (2) warming precooled milk to approximately 86° F. and cooling again to below 50° F.; and (3) homogenization. He stated spontaneous rancidity could be prevented by immediate mixing of two parts of normal milk to one part of "lipase milk."

Gould (116), in 1942, reported that low pH values adversely and permanently affected lipase activity. He found that milk lipase was a nonspecific fat-splitting enzyme capable of producing lipolysis on a wide variety of fatty substrates under favorable conditions. He also found that homogenization created a condition which greatly enhanced lipolysis as produced by pancreatic extract.

Hlynka and Hood (157), in 1942, concluded that milk having a low surface tension after holding at 5° C. would, other things being equal, have a less desirable odor than milk having a high surface tension. They stated that since surface tension was related to lipase activity and odor was a component of flavor, therefore, the flavor of milk was related to its lipase activity. The flavor sequence of a mildly and pleasantly cowy flavor in fresh drawn milk to a strong cowy flavor, and finally to a rancid flavor was stated by the authors to be supported by their results on a study of the relation of the milk lipase to milk flavor in normal milk.

Castell (53), in 1942, showed that the addition of ammonia accelerated the production of rancidity in milk as indiczted by the development of a typical butyric acidlike, rancid flavor, and the reduction of surface tension when held at 5° C. However, it was stated that from the results obtained it seemed doubtful, except in very extreme cases if the concentration of ammonia in the atmosphere of the barn where cows were being milked would ever be a major factor causing rancidity to develop in the milk or cream.

Tarassuk and Henderson (279), in 1942, found that the development of hydrolytic rancidity in raw milk by a naturally active lipase present in high concentration could be successfully prevented by mixing with 3 parts of normal milk within an hour after milking. They stated that when a milk containing a naturally active lipase was allowed after cooling to age separately and thus to become rancid, then the addition of very small amounts of this milk to a normal supply would impart the rancid flavor to the whole mixture.

In 1944, Gould (117) reported that raw milk homogenized at 700 pounds pressure was usually rancid when the acid degree of the fat was within the range of 1.5 to 2.0. He found that fat obtained from rancid milk and with acid degrees as high as 11.5 did not itself possess a rancid flavor nor did it produce a rancid flavor when homogenized into pasteurized skim milk. He stated that free fatty acids in butterfat which was obtained by churning were not responsible for the typical rancid flavor of dairy products.

Roberts and Wylie (256), in 1945, stated that the enzyme lipase, a normal constituent of cow's milk, broke down the fat into compounds which had a pronounced odor and flavor giving the characteristic rancid flavor to milk. They found little trouble with this off-flavor when cows were on pasture or had just freshened because the volume of milk was very large in proportion to the enzyme content. The proportion

of lipase increased as the quantity of milk decreased. They stated that it was this condition, and not something the cows ate, that caused the off-flavor to occur more often during the fall and winter. They recommended controlling the enzyme, as follows: (1) If near the end of the lactation period, dry the cow up; (2) mix off-flavor milk, while it is still warm, with the warm milk from two or more fresh cows or cows whose milk is still normal in flavor; and (3) heat the fresh milk to 143° F. for 30 minutes.

Kelly (175), in 1945, reported that when samples of milk were collected at frequent intervals from open cows, the data showed a definite relationship between the estrus cycle and the lipase activity.

Moore and Trout (213), in 1946, reported that 40° F. storage of homogenized milk contaminated with raw milk increased the titratable acidity, decreased the pH, and developed rancidity in the milk. It was found that, in general, at 24 hours storage it took at least 4 percent raw milk before rancidity could be detected by taste and smell. This amount was dependent on length of storage but in no case could organoleptic examination detect the addition of 0.1-percent raw milk when the mixtures were held 7 days at 40° F.

In 1948, Hetrick and Tracy (154) reported that at 145° F. approximately one-third the time was required to inactivate the lipase in milk as that required to inactivate the phosphatase enzyme, but at 185° F. the same time was required to inactivate both enzymes. They found that the time required at any temperature to inactivate lipase varied with the rate of heating to and cooling from the holding temperature.

Tarassuk and Jack (280), in 1949, stated that lipolytic flavors resulted from the presence of free fatty acids from butyric to myristic, and that there was more than one hydrolytic enzyme. They reported that hydrolysis was caused by two distinct sets of conditions. It might result from certain specific treatments of raw milk such as homogenization, violent shaking of warm milk, and warming of precooled milk to about 30° C. and cooling again below 10° C. Such treatments result in the activation of lipase, an enzyme or a group of enzymes present in raw milk. It might also result from natural lipolytically active milk usually from cows late in lactation and on dry feed, as in winter. In such milk, spontaneous lipolysis was initiated by cooling. These authors reported that, according to the data, the lipase of naturally lipolytically active milk was present in milk plasma prior to cooling. By cooling the milk, they stated that the lipase was irreversibly adsorbed on the fat globules, and the lipolysis began immediately upon the adsorption.

In 1950, Weinstein and Trout (319) concluded that milk from Ayrshire, Brown Swiss, Guernsey, Holstein, or Jersey cows was equally susceptible to rancidity when the milk was homogenized. They found low-fat milk and milk with low initial titratable acidity to become rancid upon homogenization as readily as did high-fat milk and milk with high initial titratable acidity. Storage of milk at 40°F. for 24 hours prior to homogenization was found to have no appreciable effect on homogenization-induced lipolysis.

Herrington (149), in 1950, presented a review of literature on the enzyme, lipase. This review included the work that had been done to reduce lipase activity in milk; methods of measuring lipase action; methods of inactivating milk lipase; differences in lipase action; differences in natural milks; and the practical importance of lipase. The author added his views as each section of the subject was reviewed. Part of his concluding statements were as follows: It is the products of lipase action which are objectionable, not the lipase itself. All samples of raw milk contain lipase though in many cases it appears to do no harm. The methods by which milk is handled, the accidental activation of the lipase present, is often of much more importance than variations in the amount of enzyme present. Much trouble might be avoided if more attention were paid to the danger of activating lipase by temperature changes or by agitation prior to pasteurization.

VIII. - BACTERIAL FLAVORS

It is generally recognized that the normal souring of milk is the result of the action of Streptococcus lactis, on the lactose, with lactic acid as a breakdown product. The conditions that encourage the growth of S. lactis, means of controlling its growth, and the resultant sour flavor and odor in high-acid milk and products made from such milk are also generally known and accepted. Therefore, the work concerning these factors is not discussed in this publication.

In 1897, Russell (262) reported that he isolated a pure lactic acid organism that developed in milk a taste as bitter as gall.

Guthrie (128), in 1916, stated that bacteria could cause metallic flavor. He attributed the flavor development to a member or strain of the Bacterium lactis acidi group.

Hammer (134), in 1921, found that an off-flavor in milk that had been thought to be a feed flavor was in reality due to the growth of a certain micro-organism.

Snell (272), in 1921, stated that fruity flavors in milk were bacterial in origin, and that the bacteria were carried into the milk through the medium of dust and dirt.

Hammer and Cordes (136), in 1921, determined that the caramel flavor in milk and its products was caused by Streptococcus lactis var. maltigenes. These authors reported that the flavor could be readily produced by inoculating the organism into milk or cream.

In 1928, Kelly (174) isolated caramel flavor-producing strains of bacteria from samples of milk rejected for having a cooked (caramel) flavor. Four strains were classified as variants of Streptococcus lactis.

Sadler (264), in 1929, reported isolating two strains of organisms from samples of milk that had a disagreeable and undesirable flavor. Pure cultures of the organisms produced a flat, insipid, yeasty, dough flavor in milk.

Sadler et al. (265), in 1929, found a reported feed flavor in milk to be caused by specific strains of aerobic (coli-aerogenes) gas-producing bacteria. The so-called feed flavor was associated with a penetrating, nauseating, "stable odor" of the milk. The causative organism was found to be of the aerogenes group and was isolated from corn silage.

In 1930, Newman (222) determined that the bitter flavor in three samples of milk from widely separated areas was caused by organisms of the pseudomonas group. The organisms were reported to grow at low or reduced temperatures and to be normally present in soil and water where irrigation was practiced. Proper sterilization of equipment after washing was stated as a simple and effective preventive measure.

Tracy and Ramsey (294), in 1931, showed that an objectionable malt flavor in milk might be caused by the action of a micrococcus of the aureus type. It was found that when an organism of the B. subtilis group was also present a much more pronounced malt flavor resulted. The presence of acid-forming bacteria was found to retard the development of the flavor. The malt flavor developed most rapidly at 85° to 100° F., although a more characteristic flavor was noted at 68° F. In milk held at 60° F. for 3 days the off-flavor failed to develop.

In 1933, Thurston and Olson (289) found that pasteurized milk stored at 36° to 40° F. had little bacterial growth and had developed oxidized flavor and that a sample of the same supply of milk stored at 52° to 56° F. had considerable bacterial growth and had not developed the oxidized flavor. The fact that bacterial growth retarded the development of oxidized flavor had also been reported by other workers (67, 74, 121, 141, 189, 211, and 295) as noted under Oxidized Flavor.

Leitch (191), in 1934, reported that organisms responsible for the burnt flavor in milk were frequently of internal origin and were present in the milk before it left the udder. The organism was determined to be of the lactic acid coccus type and to have the same morphological and cultural characteristics as S. lactis with the exception of its faculty to impart the burnt flavor to milk. The flavor appeared after 18 to 24 hours in a warm atmosphere. Heating freshly drawn milk to 142° F. for 30 minutes prevented the development of the off-flavor.

Bryan and Trout (50), in 1935, reported that the flavor of samples of mastitis milk resulting from streptococci infection was salty in the majority of cases.

Davis et al. (77), in 1939, found that only the faecal streptococci (S. faecalis and S. liquefacieus) produced considerable quantities of diacetyl which was recognized to be responsible for part of the aroma of dairy products.

In 1943, Claydon (56) isolated A. aerogenes from samples of bottled milk having a medicinal flavor. The isolated organism readily reproduced the off-flavor in pasteurized and sterilized milk. Improved sanitary procedures controlled the defect.

IX.- CHEMICAL FLAVORS

The recognition in 1895 (1) that drugs may be transmitted through the body of the cow into the milk has made it necessary to guard against this possible source of off-flavors. The increased use of chemical cleaners and chemical sanitizers on the dairy farm and in the dairy plant has increased the possibility of off-flavored milk due to chemicals. Fortunately, proper usage of drugs and chemicals minimizes the possible contamination of the milk, and chemical or medicinal off-flavors have not been a serious problem.

In 1931, Tracy and Ruehe (296) stated that in no case should the chlorine sterilizers used on farm and milk plant equipment be added directly to the milk. They recommended that all utensils and equipment treated with chlorine sterilizers be rinsed with uncontaminated water before adding the milk. Otherwise, they cautioned, puckery, unclean, or medicinal flavors might develop. The odor and flavor of phenol, when present in milk, was reported to be greatly intensified by the presence of chlorine in the form of sodium hypochlorite. Tracy (293), in 1936, again reported that small amounts of phenol might not cause serious flavor difficulties but that, if chlorine were used on farm utensils, the phenol flavor would be intensified manyfold.

Paley (228), in 1942, reported a case of iodine taste in milk caused by chlorine material in the pipelines and in the filler bowl. The first milk over the equipment had the iodine flavor.

In 1942, Lindquist (192) reported that milk from cows treated for suppurative inflammations by introducing iodoform preparations into the uterus must be excluded from the regular milk supply if the flavor was to be avoided in the milk. He found that the length of time the iodoform would be secreted in the milk by cows so treated varied because of individual characteristics and no time limit could be relied on as a sure means of preventing the occurrence of the flavor. Taste alone was stated to be the determining factor. One cow's milk could taint 100 to 200 gallons of mixed milk.

Nelson (220), in 1943, reported that a foreign flavor in raw milk due to feed contaminated with paradichlorobenzene intensified during a 56-hour storage period at 38° F. Pasteurization did not eliminate the off-flavor but it did not intensify as much in pasteurized milk during storage as it did in the corresponding raw milk.

Mull and Fouts (215), in 1947, added Roccal to two series of 500-milliliter portions of milk in sufficient quantities to yield 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 parts per million of Roccal. One series of samples was pasteurized immediately at 143° F. for 30 min. and cooled to 50° F. Both the raw and pasteurized series of samples were tasted immediately to determine the concentration of Roccal necessary in milk to produce a flavor that could be detected by experienced milk judges. Roccal in milk was detected by taste when 10 parts per million were present. The milk at this point had a slight puckery flavor which increased in intensity to a slight bitterness at 20 parts per million and to a very bitter flavor at 40 parts per million.

Lindquist and Donaldson (193), in 1948, determined that a bitter taste developed in the milk when a cow was fed potatoes from fields treated with benzene hexachloride. The first noticeable decrease in the off-flavor was noted 5 days after the feeding of the potatoes was discontinued, but 12 days elapsed before the milk appeared normal and did not leave a bitter taste in the mouth.

X.-MISCELLANEOUS FLAVORS

There are some flavors and factors contributing to flavor of milk that have not received major consideration but have been noted in the literature. These flavors and factors are covered under the headings that follow:

Absorbed

In 1900, Harding et al. (140) stated that vile odors absorbed after the milk had been drawn was a very real danger that for the most part had been entirely overlooked.

Marshall (208), in 1902, stated that by the interchange of gases between air and milk there was a great opportunity offered for the absorption of noxious gases by the milk unless the interchange took place in absolutely pure air.

Brueckner (49), in 1939, stated that on numerous occasions he had placed good-flavored milk in a silo overnight. The milk remained good flavored.

Trout and McMillan (303), in 1943, exposed samples of heated, homogenized, pasteurized, and raw milk at 50° and 100° F. to saturated atmospheres of various odoriferous substances from 15 to 90 minutes. Samples were examined for odors after exposure and after a 24-hour interval. The results indicated that the different milks varied somewhat in their absorptive capacity to take up the odoriferous substances, raw and pasteurized milk being slightly more susceptible to odors than homogenized and heated milk wherein creaming was inhibited. Absorption of odors was slightly greater when the fat was in a liquid state, but occurred also when the fat was in a solid state. Absorption of odors appeared to be largely a surface problem, the absorbed odors being confined largely to the upper 10 percent of a 10-gallon can of milk. When this milk was thoroughly mixed, the odor of the substance to which the milk was exposed could not be identified. As the time of exposure and the temperature of the milk were increased, the absorbed odor became more intense. When fresh, warm milk was exposed to numerous surroundings in and associated with the dairy stable, off-odors were rarely encountered except when the milk was exposed within the silo or when foreign matter actually fell into the milk. The authors concluded that the possibility of direct absorption of odors from the air by milk after being drawn and before removal from the stable would seem to have been very much over-emphasized.

Babcock (30), in 1951, reported that when milk at 40° and 90° F. was placed in open containers in a refrigerator containing freshly sliced onions, an onion flavor could not be detected, after 24 hours, in the milk that was cold whereas it was readily identified in the milk that was warm at the time it was placed in the refrigerator. The author stated that the absorption of odors as a source of abnormal flavors in milk had probably been over-emphasized.

Acidosis, Ketosis

In 1937, Barkworth and Cole (32) stated that veterinarians had assisted in explaining one cause of taint in milk by showing that in cases of cows suffering from acidosis the body fluids, including the milk, contain acetone and acetone bodies. The taint resulting from the acetone and acetone bodies offered an explanation of many cases where the milk was mildly but, to a skilled palate, definitely of abnormal flavor.

Shaw (270), in 1946, reported that a foreign flavor was imparted to the milk of cows with ketosis. He stated that in severe cases of ketosis, when the milk was not mixed with that from other cows, the sweetish flavor of acetone could be detected readily by most people.

Knodt (179), in 1950, found that the milk produced by cows with various stages of ketosis might have a typical "cowy" or "feed" flavor depending on the amount of ketone bodies which had passed from the blood into the milk.

Activated

In 1936, Weckel et al. (311) demonstrated that an unusual flavor might be induced in milk when it was sufficiently exposed to radiation transmitted through either quartz or glass. Radiation from an infrared lamp did not produce the off-flavor. Radiation of wave length 3100 to 3800 A_0 was probably responsible for the production of activated flavor. Experiments showed that the flavor originated in, and was closely associated with, the protein fraction of the milk (particularly the albumin, but also the casein). It was stated that it might be found in the fat but only because it was readily absorbed from the proteins. Irradiated cream recombined with nonirradiated skim milk produced a reconstituted milk with antirachitic potency and relatively free from activated flavor.

Weckel and Jackson (310), in 1936, and Flake et al. (91), in 1939, reported additional information on the activated flavor. They described the off-flavor resulting from undue exposure to radiation to be best described as "flat" in the incipient stage and as "burnt," "burnt feather," or "burnt protein" in the advanced stages. Their studies indicated that the oxidized flavor due to the effect of radiant energy on fat was not similar to the "activated" flavor. The activated flavor originated in or was closely associated with the protein fraction of the milk. They determined that heating milk to temperatures above 150° to 160° F. and cooling enhanced the activated flavor. When irradiation and homogenization were both used in processing milk, better results were obtained if irradiation preceded homogenization.

In 1940, Flake et al. (89,90) established a method for isolating and concentrating the highly volatile flavor and odor material believed responsible for the typical activated flavor in milk. Analysis of the material so isolated was not possible because of the small quantity obtained. These authors found that the results of irradiation of the amino

acids indicated that cystine, methionine, tryptophane, and histidine might be important contributors to the activated flavor.

Kenney (169), in 1949, reported results that indicated that the activated flavor of excessively irradiated milk and the sunlight flavor were not formed in a similar manner.

Chalky

Moore and Trout (214), in 1947, reported a thick, viscous chalky-flavored homogenized milk was encountered in processing and distributing bottled, high-testing (4.5 to 4.7 percent fat) homogenized milk. The defect was associated with homogenizing, following pasteurization of vat-cooled milk at a temperature around 80° F.

Chloride-lactose

In 1929, Roadhouse and Koestler (255) reported that the chloride-lactose relation was one of the most important bases of milk taste. Milk samples with a high chloride-lactose ratio were judged by taste less favorably than those of like origin where the chloride-lactose ratio was relatively low.

Roadhouse and Henderson (254), in 1930, stated that, in general, the taste score of milk followed the trend of the lactose content, the taste score lowering and rising as the lactose percent decreased and increased. It was also noted that there was a correlation between the lowering of the taste score and lactose percentage and an increase in the chloride content.

Color

Garrett et al. (105), in 1939, reported a significant positive correlation between the yellow color and the flavor of freshly drawn milk from individual cows.

Fishy

Harding et al. (140), in 1900, found a highly disagreeable fishy flavor in the products of a dairy. The defect was traced to a single apparently healthy cow. Cause for the defect was not determined.

Freezing

Reid (244), in 1927, added sterilized solutions of wash water, fly repellent, ragweed, silage, alfalfa, molasses, onions, animal heat, woody, oily, gasoline, metallic, and feces to samples of fresh 3.7-percent milk. The samples were frozen at a constant temperature of 10° F. for 3 hours and then thawed. It was found that freezing intensified the flavors.

Inhaled

Babcock (26), in 1925, and MacDonald and Jacob (203), in 1928, reported that inhalation of the volatile substances from wild garlic produced a strong garlic flavor and odor in the milk in a short time.

In 1942, Petersen and Brereton (233) studied the effects of inhaling the odors from thirteen substances on the flavor of milk. Inhalation of turpentine, paradichlorobenzene, camphor, or vanillin caused flavoring of the milk characteristic of each of these compounds. Inhalation of benzaldehyde, onion, and garlic caused a change in the flavor of the milk which was not characteristic of the compound. Inhalation of odors from corn silage, alfalfa silage, and decomposing manure produced "off-flavors" in the milk. Inhalation of synthetic orchid or scrapings of Roquefort cheese produced no detectable "off-flavor" in milk.

Phospholipid

In 1935, Thurston and Barnhart (286) reported that phospholipids of milk contributed to the richness of flavor in milk products.

Sediment

Marquardt (205), in 1946, demonstrated that when more than 25 percent of the milk received contained excessive (No. 4 sediment disc) amounts of sediment, an unclean flavor developed in a mixed tank of milk. The flavor of clean milk deteriorated slower than did unclean milk when subjected to 4- to 6-hour holding periods at temperatures of 70° F. The flavor of the milk was improved as the percentage of clean milk delivered was increased.

LITERATURE CITED

(1) Allen, E. W.
1895. A Review of Recent Work on Dairying. Expt. Sta. Rec. (1893-94) 5: 943-974.

(2) Allo, A. V.
1940. Cress Taint Can be Overcome. N. Z. Jour. Agr. 61 (4): 277-279.

(3) Anderson, E. O.
1937. Variations in Susceptibility of Milk as Secreted by the Cow. Proc. 30th Ann. Conv. Intern. Assoc. Milk Dealers, Lab. Sec. (pp. 153-164.)

(4) Anderson, E. O.
1939. Preventing Development of Oxidized Flavor in Milk Through the Addition of Small Amounts of Pancreatic Enzyme. The Milk Dealer 29 (3): 32-42.

(5) Anderson, E. O., Dowd, L. R., and Stuewer, C. A.
1937. Relation of Acidity of Milk to Oxidized Flavor. Food Research 2 (2): 143-150.

(6) Anderson, J. A.
1936. Off-Flavored Milk - A Problem of Animal Nutrition. The Milk Dealer. 26: 60-66. Oct.

(7) Anderson, J. A.
1937. The Influence of the Ration on Milk Flavor. 25th Ann. Rept. Int. Assoc. Dairy and Milk Inspectors pp. 223-238.

(8) Anderson, J. A.
1936. The Cause of Oxidized and Rancid Flavors in Raw Milk. Proc. 29th Ann. Conv. Int. Assoc. Milk Dealers Lab. Sec. (pp. 117-134.)

(9) Anderson, J. A.
1934. Bitter Milk and Cream. Proc. 27th Ann. Conv. Int. Assoc. Milk Dealers Lab. Sec. (pp. 17-27.)

(10) Ann. Rept. United States Dept. Agr.
1929. Report of the Chief of the Bureau of Dairy Industry. (p. 18.)

(11) Anonymous.
1922. Will Sweet Clover Taint the Milk? Farmers Advocate and Home Magazine. 57: 612. May

(12) Anonymous.
1938. Steam vs. Hot Water as a Heating Medium for Pasteurizing Milk. Milk Dealer 28 (2): 52, 54.

(13) Anonymous.
1939. Carrot Weed - A Serious Cause of Taint in Milk. Agr. Gaz. New South Wales 50: 49-50. Jan.

(14) Anonymous.
1949. Oxidized Flavor in Milk. Agricultural Research in Texas, 1947 to 1949 Tex. Agr. Expt. Sta. Rept.

(15) Arnett, C. N., and Tretsven, O.
1917. Sunflower Silage for Dairy Cows - A Preliminary Report Mont. Agr. Expt. Sta. Bull. No. 118.

(16) Aurand, L. W., and Moore, J. L.
1951. No Easy Remedy for Wild Onion Flavor in Milk. N. C. Agr. Expt. Sta. Res. and Farming 10 (1): 5.

(17) Ayers, S. H., and Johnson, W. T.
1914. Removal of Garlic Flavor from Milk and Cream. U. S. Dept. Agr. Farmers' Bull. No. 608.

(18) Babcock, C. J.
1923. Effect of Feeding Green Alfalfa and Green Corn on Flavor and Odor of Milk. U. S. Dept. Agr. Bull. No. 1190.

(19) Babcock, C. J.
1927. Effect of Some Succulent Feeds on the Flavor and Odor of Milk. U. S. Dept. Agr. Tech. Bull. No. 9.

(20) Babcock, C. J.
1924. Effect of Feeding Cabbage and Potatoes on Flavor and Odor of Milk. U. S. Dept. Agr. Bull. No. 1297.

(21) Babcock, C. J.
1925. Effect of Feeding Green Rye and Green Cowpeas on the Flavor and Odor of Milk. U. S. Dept. Agr. Bull. No. 1342.

(22) Babcock, C. J.
1923. Effect of Feeding Turnips on the Flavor and Odor of Milk. U. S. Dept. Agr. Bull. No. 1208.

(23) Babcock, C. J.
1928. Preventing Feed Flavors and Odors in Milk. U. S. Dept. Agr. Leaflet No. 25.

(24) Babcock, C. J.
1938. Feed Flavors in Milk and Milk Products. Jour. Dairy Sci. 21 (10): 661-668.

(25) Babcock, C. J.
1929. Effect of Bitterweed on Dairy Products. U. S. Dept. Agr. BDIM No. 440.

(26) Babcock, C. J.
1925. Effect of Garlic on the Flavor and Odor of Milk. U. S. Dept. Agr. Bull. No. 1326.

(27) Babcock, C. J.
1942. Effect of Homogenization on the Curd Tension, Digestibility, and Keeping Quality of Milk. U. S. Dept. Agr. Tech. Bull. No. 832.

(28) Babcock, C. J.
1939. The Pasteurization of Milk. U. S. Dept. Agr. Leaflet No. 177. (sl. rev. 1949)

(29) Babcock, C. J.
1934. The Effect of Homogenization on Certain Characteristics of Milk. U. S. Dept. Agr. Tech. Bull. No. 438.

(30) Babcock, C. J.
1951. Common Causes of Off-Flavored Milk and Their Control. Jour. Milk and Food Tech. 14 (2): 68-70.

(31) Babcock, C. J., and Haller, H. S.
1943. Effect of Some Silages on the Copper Tolerance of Pasteurized Milk. Jour. Dairy Sci. 26 (7): 563-570.

(32) Barkworth, H., and Cole, L. W. L.
1937. Acidosis and Off-Flavored Milk. Nature 140 (3528): 324.

(33) Barthel, C.
1916. Experiments in Sweden on the Prolonged Pasteurization of Milk. Int. Rev. Sci. and Practice of Agr. 7 (1): 143-146.

(34) Bartlett, J. W.
1940. Factors Affecting Color and Flavor of Guernsey Milk. Guernsey Breeders' Jour. 57: 96-97. Jan.

(35) Bartley, E. E., Chin, J. W., Cannon, C. J., and Bird, E. W.
1950. The Influence of Cracked Soybeans, Soybean Hay and Various Kinds of Containers on the Flavor of Milk. Jour. Dairy Sci. 33 (1): 28-37.

(36) Beck, G. H., Whitnah, C. W., and Martin, W. H.
1939. Relation of Vitamin C, Lecithin, and Carotene of Milk to the Development of Oxidized Flavor. Jour. Dairy Sci. 22 (1): 17-29.

(37) Bradley, R.
1757. A General Treatise of Agriculture. London.

(38) Briggs, L. H.
1931. The Autoxidation of Butterfat. Jour. Dairy Res. 3 (1): 70-79.

(39) Brown, W. C., and Dustman, R. B.
1939. Oxidized Flavor in Milk. VI. A Study of the Relation of Titratable Acidity to Metal-Developed Oxidized Flavor in Milk. Jour. Dairy Sci. 22 (1): 31-35.

(40) Brown, W. C., Dustman, R. B., and Thurston, L. M.
1937. Oxidized Flavor in Milk V. The Effect of Metal-Developed Oxidized Flavor on the Iodine Number of the Milk Fat. Jour. Dairy Sci. 20 (9): 599-604.

(41) Brown, W. C., Dustman, R. B., and Weakley, C. E.
1941. Oxidized Flavor in Milk. VIII. The Effect of The Degree of Saturation of Fat in the Ration of the Cow Upon the Iodine Number of the Butterfat and the Susceptibility of the Milk to Metal-Induced Oxidized Flavor. Jour. Dairy Sci. 24 (4): 265-275.

(42) Brown, W. C., and Olson, F. C.
1942. Oxidized Flavor in Milk. XII. Further Studies of Ascorbic Acid Mechanisms in the Production of Oxidized Flavor in Milk. Jour. Dairy Sci. 25 (12): 1041-1050.

(43) Brown, W. C., Thurston, L. M., and Dustman, R. B.
1936. Oxidized Flavor in Milk. III. The Time of Copper Contamination During Production and Processing, and Aeration versus No Aeration as Related to Oxidized Flavor Development. Jour. Dairy Sci. 19 (12): 753-760.

(44) Brown, W. C., Thurston, L. M., and Dustman, R. B.
1937. Oxidized Flavor in Milk. IV. Studies of The Relation of the Feed of the Cow to Oxidized Flavor. Jour. Dairy Sci. 20 (3): 133-145.

(45) Brown, W. C., VanLandingham, A. H., and Weakley, C. E.
1939. Oxidized Flavor in Milk. VII. Studies of the Effect of Carotene and Ascorbic Acid in the Feed of the Cow on the Susceptibility of the Milk To Metal-Induced Oxidized Flavor. Jour. Dairy Sci. 22 (5): 345-351.

(46) Brown, W. C., VanLandingham, A. H., and Weakley, C. E.
1941. Oxidized Flavor in Milk. IX. The Effect of the Quality of Hay and Early Stage of Lactation on the Carotene Content of Butterfat and on the Ascorbic Acid Content of the Milk and Their Relationship to the Development of Metal-Induced Oxidized Flavor. Jour. Dairy Sci. 24 (11): 925-935.

(47) Brown, W. C., VanLandingham, A. H., and Weakley, C. E.
1941. Oxidized Flavor in Milk. X. The Effect of Feeding Potassium Iodine Supplement to Dairy Cows on the Carotene Content of the Butterfat and on the Ascorbic Acid Content of the Milk and the Relationship to Metal-Induced Oxidized Flavor. Jour. Dairy Sci. 24 (12): 1035-1039.

(48) Browne, C. A.
1925. The Spontaneous Decomposition of Butterfat. Ind. Eng. Chem. 17 (1): 44-47.

(49) Brueckner, H. J.
1939. Milk Plant Problems. The Amer. Prod. Rev. 87: 577. Mar.

(50) Bryan, C. S., and Trout, G. M.
1935. The Influence of Streptococci Infection of the Udder on the Flavor, Chloride Content, and Bacteriological Quality of the Milk Produced. Jour. Dairy Sci. 18 (12): 777-792.

(51) Burgwald, L. H.
1935. Off Flavors in Milk. Amer. Cry. and Poultry Prod. Rev. 79: 916. April

(52) Button, F. C.
1933. Cardboard or Tallowy Flavors in Milk. N. J. Agr. Expt. Sta. Ext. Bull. No. 110.

(53) Castell, C. H.
1942. The Influence of Ammonia on the Development of Rancidity in Milk. Jour. Milk Tech. 5 (4): 195-201.

(54) Chilson, W. H.
1935. What Causes Most Common Off Flavors of Market Milk? Milk Plant Monthly 24 (11) (12): 24-28 and 30-34.

(55) Chilson, W. H., Martin, W. H., and Whitnah, C. H.
1950. Use of Propyl Gallate to Defer Development of Oxidized Flavor In Market Milk. Jour. Dairy Sci. 33 (12): 925-928.

(56) Claydon, T. J.
1943. An Outbreak of a Medicinal Flavor in Market Milk Caused by Aerobacter Aerogenes. Jour. Dairy Sci. 26 (7): 587-590.

(57) Cone, J. F., and Babcock, C. J.
1943. The Role of Oxidase-Producing Bacteria in the Development of Oxidized Flavor in Milk. Jour. Dairy Sci. 26 (1): 1-6.

(58) Corbett, W. J.
1942. Study of Oxidized Flavor in Milk. Abstract. Ph. D. Thesis Univ. Ill.

(59) Corbett, W. J., and Tracy, P. H.
1943. The Incidence of Oxidized Flavor in the Milk of Individual Cows Within One Herd. Jour. Dairy Sci. 26 (12): 1095-1106.

(60) Corbett, W. J., and Tracy, P. H.
1940. Effect of Condensing on the Development of Oxidized Flavor. Jour. Dairy Sci. 23 (3): 209-214.

(61) Corbett, W. J., and Tracy, P. H.
1943. Relation of Degree of Saturation of Milk Fat to Development of Oxidized Flavor. Jour. Dairy Sci. 26 (5): 419-427.

(62) Cranfield, H. T., and Mackintosh, J.
1935. Taint in Milk During the Feeding of Molassed Beet Pulp. The Jour. Ministry Agr. 52 (6): 551-560.

(63) Crowe, L. K.
1952. Some Troublesome Flavors in Our Market Milk. Milk Plant Monthly 41 (11): 74-78.

(64) Dahlberg, A. C., Adams, H. S., and Held, M. E.
1953. Sanitary Milk Control and its relation to the Sanitary, Nutritive and Other Qualities of Milk. National Academy of Sciences, National Res. Pub. No. 250.

(65) Dahlberg, A. C., and Carpenter, D. C.
1936. The Influence of Method of Sterilizing Equipment Upon Development of Oxidized Flavor in Milk. Jour. Dairy Sci. 19 (8): 541-551.

(66) Dahle, C. D.
1936. Tallowy Flavor in Milk. Pa. Agr. Expt. Sta. Bull. No. 336.

(67) Dahle, C. D.
1937. Off Flavor of Milk. Pa. Agr. Expt. Sta. Bull. No. 352.

(68) Dahle, C. D.
1935. Tallowy Flavor in Milk. Pa. Agr. Expt. Sta. Bull. No. 320.

(69) Dahle, C. D.
1941. Cause and Prevention of Oxidized Flavor in Milk. Milk Plant Monthly 30 (9): 29-34.

(70) Dahle, C. D., and Josephson, D. V.
1939. Treatment of Paper Milk Bottles to Delay or Prevent the Oxidized Flavor of Milk. The Milk Dealer 28: 39. Aug.

(71) Dahle, C. D., and Palmer, L. S.
1937. The Oxidized Flavor in Milk from the Individual Cow. Pa. Agr. Exp. Sta. Bull. No. 347.

(72) Davies, J. E.
1939. Control of Feed Flavor - Trial Reveals no Loss in Production when Cows are Spelled Before Milking. N. Z. Jour. Agr. 59: 1-3. July

(73) Davies, W. L.
1936. The Fishy Flavor of Milk Caused by Feeding Beet By-Products. Agr. Progress 13: 112-115.

(74) Davies, W. L.
1933. Metallic Contamination in Processing. The Milk Industry 13 (9): 55, 57.

(75) Davies, W. L.
1930. Causes of Deterioration of Fats and Oils. Oil and Fat Ind. 7 (11) (12): 427-431, 453-457.

(76) Davies, W. L.
1931. The Action of Strong Sunlight on Milk. Certified Milk 6 (61): 4-5.

(77) Davis, J. G., Rogers, H. J., and Thiel, C. C.
1939. Letters to the Editor - Production of Diacetyl by Faecal Streptococci. Nature 143: 558. April.

(78) Dean, H. H.
1897. Report of Professor of Dairy Husbandry. Part VI. 23rd.Ann. Rept. Ontario Agr. College and Expt. Farm.

(79) Dice, J. R.
1944. Weed Flavors in Dairy Products. N. Dak. Agr. Expt. Sta. Bi-monthly Bull. 6 (4): 6-9.

(80) Doan, F. J.
1938. Problems Relating to Homogenized Milk. Jour. Milk Tech. 1 (6): 20-25.

(81) Doan, F. J., and Miller, G. M.
1940. Trypsin - An Anti-Oxygen for Milk. Milk Plant Monthly 29 (9): 42-47.

(82) Doan, F. J., and Myers, C. H.
1936. Effect of Sunlight on Some Milk and Cream Products. Milk Dealer 26 (1): 76-87.

(83) Donauer, M.
1922. The Action of Metals on Milk. The Ice Cream Rev. 5: 78, 84. Feb.

(84) Dunkley, W. L.
1951. Evaluation of the Thiobarbituric Acid Test as a Measure of Oxidized Flavor in Milk. Food Tech. 5 (8): 342-346.

(85) Echles, C. H., and Shaw, R. H.
1913. United States Dept. Agr. BAI Bull. No. 155.

(86) England, C. W., and Wiedemer, A. P.
1941. Studies on the Antioxygenic Effect of Oat Flour Treated Milk Bottles for Milk Exposed to Sunlight. The Milk Dealer 31 (3): 33-36.

(87) Epple, W. F., and Horrall, B. E.
1943. The Relation of Copper and Ascorbic Acid to Oxidized Flavor in Market Milk. Jour. Dairy Sci. 26 (6): 525-532.

(88) Fink, G. G., and Rohrman, F. A.
1932. The Corrosion of Metals by Milk. Jour. Dairy Sci. 15 (1): 73-86.

(89) Flake, J. C., Jackson, H. C., and Weckel, K. G.
1940. Isolation of Substances Responsible for the Activated Flavor of Milk. Jour. Dairy Sci. 23 (11): 1087-1095.

(90) Flake, J. C., Jackson, H. C., and Weckel, K. G.
1940. Studies of the Source-Origin of Activated Flavors in Milk. Jour. Dairy Sci. 23 (11): 1079-1086.

(91) Flake, J. C., Weckel, K. G., and Jackson, H. C.
1939. Studies on the Activated Flavor of Milk. Jour. Dairy Sci. 22 (3): 153-161.

(92) Forster, T. L., and Sommer, H. H.
1951. Manganese, Trypsin, Milk Proteins and the Susceptibility of Milk to Oxidized Flavor Development. Jour. Dairy Sci. 34 (10): 992-1002.

(93) Fraser, W. J.
1905. Crops for the Silo, Cost of Filling, and Effect of Silage on the Flavor of Milk. Ill. Agr. Expt. Sta. Bull. No. 101.

(94) Frazier, W. C.
1928. A Defect in Milk Due to Light. Jour. Dairy Sci. 11: 375-379. Sept.

(95) Frye, J. B., Jr., Cannon, C. Y., and Bird, E. W.
1950. The Influence of Cracked Soybeans and Other Factors Upon Flavor of Milk and the Iodine Value of Milk Fat. Jour. Dairy Sci. 33 (4): 205-215.

(96) Gamble, J. A. and Kelly, E.
1922. The Effect of Silage on the Flavor and Odor of Milk. U. S. Dept. Agr. Bull. No. 1097.

(97) Garrett, O. F.
1938. T. A. - Grass Silage and Yellow Color. Guernsey Breeders' Jour. 54: 98. July.

(98) Garrett, O. F.
1939. The Production of Good-Flavored Milk. N. J. Agr. Expt. Sta. Ext. Bull. No. 207. 1939.

(99) Garrett, O. F.
1941. Some Factors Affecting the Stability of Certain Milk Properties V. Interrelation of Certain Metals and Metallic Ions and the Development of Oxidized Flavor in Milk. Jour. Dairy Sci. 24 (2): 103-109.

(100) Garrett, O. F.
1937. Cardboard Flavor. N. J. Agr. 19: 3. March-April.

(101) Garrett, O. F.
1940. The Antioxidative Action of Finely Milled Oat Flour on Milk. Milk Plant Monthly 29 (2): 40,42, 80.

(102) Garrett, O. F., Arnold, R. B., and Hartman, G. H.
1941. Some Factors Affecting the Stability of Certain Milk Properties. IV. A Comparison of Seven Different Roughages on the Color and Flavor of Milk. Jour. Dairy Sci. 24 (1): 71-83.

(103) Garrett, O. F., and Bender, C. B.
1940. The Production and Control of Good Flavor in Milk. Milk Plant Monthly 29: 23-25. Jan.

(104) Garrett, O. F., Bender, C. B., and Tucker, H. H.
1937. Relation of Grass Silage to the Color, Vitamin C and Flavor in Milk from Individual Cows. Jour. Dairy Sci. 20 (7): 426-427.

(105) Garrett, O. F., Hartman, G. H., and Arnold, R. B.
1939. Some Factors Affecting the Stability of Certain Milk Properties I. Effect of Succulent Roughages on Flavor. Jour. Dairy Sci. 22 (9): 717-727.

(106) Gaul, L. E., and Staud, A. H.
1935. Metal-Free Dairy Products an Essential Adjunct of Metal-Free Treatment. Certified Milk 10 (107): 3-5.

(107) Gebhardt, H. T., and Sommer, H. H.
1931. The Solubility of Metals in Milk. I. The Solubility of Copper Under Various Conditions. Jour. Dairy Sci. 14 (5): 416-446.

(108) Gebhardt, H. T., and Sommer, H. H.
1931. Residual-Current Measurements in Control of Metal Solution in Milk. Ind. Eng. Chem. (Anal. Ed.) 3 (4): 414-418.

(109) Gebhardt, H. T., and Sommer, H. H.
1932. The Solubility of Metals in Milk. II. Submerged Corrosion Tests of Various Metals in Milk. Jour. Dairy Sci. 15 (1): 42-61.

(110) Golding, J., and Feilman, E.
1905. Taint in Milk Due to Contamination by Copper. Jour. Soc. Chem. Ind. 24 (24): 1285-1286.

(111) Gould, I. A.
1939. Cooked and Oxidized Flavors of Milk as Affected by Ferrous Iron. Jour. Dairy Sci. 22 (12): 1017-1023.

(112) Gould, I. A.
1940. Control of Flavor in Milk Heated to High Temperature. The Milk Dealer 29 (8): 70.

(113) Gould, I. A.
1940. The Relationship Between the Cooked Flavor and Peroxidase Reactions in Milk, Skimmilk and Cream. Jour. Dairy Sci. 23 (1): 37-46.

(114) Gould, I. A.
1940. Lipolysis in Raw Milk. Influence of Homogenization Temperature. Ind. Eng. Chem. 32 (6): 876-877.

(115) Gould, I. A.
1941. Effect of Certain Factors Upon Lipolysis in Homogenized Raw Milk and Cream. Jour. Dairy Sci. 24 (9): 779-788.

(116) Gould, I. A.
1942. Influence of pH, Type of Fat, and Pancreatic Extract Upon Lipolysis in Homogenized Milk. Jour. Dairy Sci. 25 (10): 869-876.

(117) Gould, I. A.
1944. Relationship of Fat Acidity to Rancidity in Homogenized Raw Milk. Jour. Dairy Sci. 27 (3): 167-172.

(118) Gould, I. A., Fox, W. K., and Trout, G. M.
1940. Influence of Feeds on Lecithin Content of Milk and Possible Relationship of Lecithin Content to Susceptibility of Milk to Copper-Induced Oxidized Flavor. Food Research 5 (2): 131-139.

(119) Gould, I. A., and Sommer, H. H.
1939. Effect of Heat on Milk With Especial Reference to the Cooked Flavor. Mich. Agr. Expt. Sta. Tech. Bull. No. 164.

(120) Gould, I. A., and Trout, G. M.
1939. Lipase Action in Mixtures of Raw and Pasteurized Homogenized Milk. Mich. Agr. Expt. Sta. Qtr. Bull. 22.

(121) Greenbank, G. R.
1940. Variation in the Oxidation-Reduction Potential as a Cause for the Oxidized Flavor in Milk. Jour. Dairy Sci. 23 (8): 725-744.

(122) Greenbank, G. R.
1936. Control of the Oxidized Flavor in Milk. Proc. 29th Ann. Conv. Int. Assoc. Milk Dealers Lab. Sec. (pp. 101-116.)

(123) Greenbank, G. R., and Holm, G. E.
1934. Antioxidants for Fats and Oils. Ind. Engin. Chem. (Ind. Ed.) 26: 243-245.

(124) Greenbank, G. R., and Holm, G. E.
1930. A Photochemical Method for Measuring Susceptibility of Fats and Oils to Oxidation. Ind. Engin. Chem. (Anal. Ed.) 2: 9-10.

(125) Guthrie, E. S.
1946. The Effect of Feeding Cod-Liver Oil on the Oxidized and Goaty Flavors and Vitamin C in Milk. Jour. Dairy Sci. 29 (6): 349-358.

(126) Guthrie, E. S.
1946. The Results of Deaeration on the Oxygen, Vitamin C and the Oxidized Flavors of Milk. Jour. Dairy Sci. 29 (6): 359-369.

(127) Guthrie, E. S.
1929. Determines the Effect of Milk on Metals and Glass. The Milk Dealer 18 (10): 72, 136.

(128) Guthrie, E. S.
1916. Metallic Flavor in Dairy Products. N. Y. (Cornell) Agr. Expt. Sta. Bull. No. 373.

(129) Guthrie, E. S.
1929. Metal Corrosion and Milk Flavor. N. Y. Prod. Rev. and Amer. Cry. 67 (9): 416-418.

(130) Guthrie, E. S., and Brueckner, H. J.
1933. The Cow As a Source of "Oxidized" Flavors in Milk. N. Y. State Agr. Expt. Sta. Bull. No. 606.

(131) Guthrie, E. S., Hand, D. B., and Sharp, P. F.
1938. Oxygen in Milk and Its Relation to Destruction of Vitamin C and the Development of the Oxidized Flavor. 12th Ann. Rept. N. Y. State Assoc. of Dairy and Milk Inspectors (pp. 101-110.)

(132) Guthrie, E. S., and Krukovsky, V. N.
1949. Effect of the Quick and Complete Elimination of Vitamin C on The Development of the Oxidized Flavors in Homogenized Milk with Special Reference to the Action of Daylight. Jour. Dairy Sci. 32 (9): 786-803.

(133) Guthrie, E. S., Roadhouse, C. L., and Richardson, G. A.
1931. Corrosion of Metals by Milk and its Relation to the Oxidized Flavors of Milk. Hilgardia (Jour. Agr . Sci. Calif. Agr. Expt. Sta.) 5 (14): 425-453.

(134) Hammer, B. W.
1921. Butter Flavors. N. Y. Prod. Rev. and Amer. Cry. 53: 150. Nov.

(135) Hammer, B. W., and Cordes, W. A.
1920. A Study of Brown Glass Milk Bottles With Special Reference to Their Use in Preventing Abnormal Flavors Due to Light. Iowa Agr. Expt. Sta. Res. Bull. No. 64.

(136) Hammer, B. W., and Cordes, W. A.
1921. Burnt or Caramel Flavor of Dairy Products. Iowa Agr. Expt. Sta. Res. Bull. No. 68.

(137) Hand, D. B., Guthrie, E. S., and Sharp, P. F.
1938. Effect of Oxygen, Light, and Lactoflavin on the Oxidation of Vitamin C in Milk. Sci. 87 (2263): 439-441.

(138) Hankinson, C. L., Ellertson, M. E., and Glein, W.
1946. Studies of the Effect of Heat on Milk Dialysates. Jour. Dairy Sci. 29 (10): 727-736.

(139) Hansen, A. A.
1929. Pasture Weeds and Tainted Milk. Hoard's Dairyman 74: 670. July.

(140) Harding, H. A., Rogers, L. A., and Smith, G. A.
1900. Notes on Some Dairy Troubles. N. Y. Agr. Expt. Sta. Bull. No. 183.

(141) Harley, W., and Ridgway, J.
1829. Harleian Dairy System. (pp. 116-117) London.

(142) Hartman, G. H., and Garrett, O. F.
1942. Development of Oxidized Flavor and the Speed of Oxidation of Ascorbic Acid in Milk. Jour. Milk Tech. 5 (2): 86-87.

(143) Hartman, G. H., and Garrett, O. F.
1943. Some Factors Affecting the Stability of Certain Milk Properties. VI. Relation of the Concentration of Dissolved Oxygen to the Oxidation of Ascorbic Acid and to the Development of Oxidized Flavor in Milk. Jour. Dairy Sci. 26 (4): 337-342.

(144) Henderson, J. L., and Roadhouse, C. L.
1940. The Influence of "White-Metal" Copper-Nickel Alloys on the Flavor of Milk. Jour. Dairy Sci. 23 (3): 215-220.

(145) Henderson, J. L., and Roadhouse, C. L.
1934. Factors Influencing the Initial Induction Period in the Oxidation of Milk Fat. Jour. Dairy Sci. 17 (4): 321-330.

(146) Hening, J. C., and Dahlberg, A. C.
1938. The Effect of Feeding Mangels or Dried Beet Pulp to Cows on the Development of Oxidized Flavor in Milk. Jour. Dairy Sci. 21 (7): 345-352.

(147) Hening, J. C., and Dahlberg, A. C.
1939. The Flavor of Milk as Affected by Season, Age, and the Level of Feeding Dairy Cows. Jour. Dairy Sci. 22 (11): 883-888.

(148) Herreid, E. O., Ruskin, B., Clark, G. L., and Parks, T. B.
1952. Ascorbic Acid and Riboflavin Destruction and Flavor Development in Milk Exposed to the Sun in Amber, Clear, Paper and Ruby Bottles. Jour. Dairy Sci. 35 (9): 772-778.

(149) Herrington, B. L.
1950. Lipase in Dairy Products with Special Reference to its Effect on Flavors and its Control. Proc. 43rd Ann. Conv. Milk Ind. Foundation Lab. Sec. (pp. 30-45.)

(150) Herrington, B. L., and Krukovsky, V. N.
1939. Studies of Lipase Action. I. Lipase Action in Normal Milk. Jour. Dairy Sci. 22 (3): 127-135.

(151) Herrington, B. L., and Krukovsky, V. N.
1939. Studies of Lipase Action. II. The Activation of Milk Lipase by Temperature Changes. Jour. Dairy Sci. 22 (3): 137-147.

(152) Herrington, B. L., and Krukovsky, V. N.
1939. Studies of Lipase Action. III. Lipase Action in the Milk of Individual Cows. Jour. Dairy Sci. 22 (3): 149-152.

(153) Herrington, B. L. and Krukovsky, V. N.
1942. Studies of Lipase Action. VII. The Influence of the Rate of Cooling Upon the Subsequent Rate of Lipolysis in Milk Stored at Low Temperatures. Jour. Dairy Sci. 25 (3): 241-248.

(154) Hetrick, J. H., and Tracy, P. H.
1948. Effect of High-Temperature Short-Time Heat Treatment on Some Properties of Milk. II. Inactivation of the Lipase Enzyme. Jour. Dairy Sci. 31 (10): 881-887.

(155) Hileman, J. L.
1933. Recent Observations with Reference to Milk Flavor. 7th Ann. Rept. N. Y. State Assoc. Dairy and Milk Inspectors (pp. 49-52.)

(156) Hileman, J. L., and Courtney, Eleanor.
1935. Seasonal Variations in the Lipase Content of Milk. Jour. Dairy Sci. 18 (4): 247-257.

(157) Hlynka, I., and Hood, E. G.
1942. Milk Lipase and Milk Flavor. Jour. Dairy Sci. 25 (5): 389-392.

(158) Holland, R. F., and Dahlberg, A. C.
1940. The Effect of the Time and Temperature of Pasteurization Upon Some of the Properties and Constituents of Milk. N. Y. Agr. Expt. Sta. Tech. Bull. No. 254.

(159) Holm, G. E.
1951. Oxidative Deterioration in Dairy Products. Milk Plant Monthly 40 (11): 38-42.

(160) Hunziker, O. F.
1928. Metals and Their Various Influence on Milk. Jour. Dept. Agr. of Victoria 26 (11): 679-692.

(161) Hunziker, O. F.
1923. Selection of Metals in the Construction of Dairy Equipment Proc. World's Dairy Cong. 2: 1189-1202.

(162) Hunziker, O. F.
1930. Effect of Metals on Milk. N. Y. Prod. Rev. and Amer. Cry. 69 (11): 526-530.

(163) Hunziker, O. F.
1925. Pasteurization in the Dairy Industry. The Cry. and Milk Plant Monthly 14 (5): 47-51.

(164) Hunziker, O. F., Cordes, W. A., and Nissen, B. H.
1929. Metals in Dairy Equipment-Metallic Corrosion in Milk Products and its Effect on Flavor. Jour. Dairy Sci. 12 (2): 140-181.

(165) Hutton, J. T., and Patton, S.
1952. The Origin of Sulphydryl Groups in Milk Proteins and Their Contributions to "Cooked" Flavor. Jour. Dairy Sci. 35 (8): 699-705.

(166) Josephson, D. V., Burgwald, L. H., and Stoltz, R. B.
1946. The Effect of Route Delivery on the Flavor, Riboflavin and Ascorbic Acid Content of Milk. Jour. Dairy Sci. 29 (5): 273-284.

(167) Josephson, D. V., and Dahle, C. D.
1941. Preventing Oxidized Flavor in Milk. The Milk Dealer 30 (11): 29, 60-62.

(168) Josephson, D. V., and Doan, F. J.
1939. Observations on Cooked Flavor in Milk - Its Source and Significance. The Milk Dealer 29 (2): 35, 54.

(169) Keeney, D. G.
1949. The "Sunlight" Flavor in Milk. Milk Plant Monthly 38 (10): 54.
(170) Keeney, M., and Doan, F. J.
1951. Studies on Oxidized Milk. I. Observations on the Chemical Properties of the Volatile Flavor Material from Oxidized Milk Fat. Jour. Dairy Sci. 34 (8): 713-718.
(171) Keeney, M.,and Doan, F. J.
1951. Studies on Oxidized Milk. II. Preparation of 2, 4-Dinitrophenylhydrazones from the Volatile Material from Oxidized Milk Fat. Jour. Dairy Sci. 34 (8): 719-727.
(172) Keeney, M., and Doan, F. J.
1951. Studies on Oxidized Milk. III. Chemical and Organoleptic Properties of Volatile Material Obtained by Fractionation with Various Solvents and Girard's Reagent. Jour. Dairy Sci. 34 (8): 728-734.
(173) Keith, J. I.
1939. Observations on the Development of Rancidity in Sweet Milk, Cream, Butter. The Milk Dealer 28 (4): 82.
(174) Kelly, C. D.
1928. A Study of Some Types of Bacteria Which Produce a "Caramel" Flavor in Milk. Transactions Royal Soc. Canada Sec. 5, Vol. 22 (2): 227-232.
(175) Kelly, P. L.
1945. Milk Lipase Activity: A Method for Its Determination and Its Relationship to the Estrual Cycle. Jour. Dairy Sci. 28 (11): 803-820.
(176) Kende, S.
1931. Reasons For and Combating of "Oily" Milk Defects ("Oleinase", a New Enzyme in the Milk). Proc. 9th Inter. Dairy Cong. Sub. 3 Paper 137.
(177) King, F. H.
1897. The Construction of Silos and the Making and Handling of Silage. Wis. Agr. Expt. Sta. Bull. No. 59.
(178) Knisely, A. L.
1903. Feeding Silage to Cows. Oreg. Agr.Expt. Sta. 15th Ann. Rept. (pp. 44-45.)
(179) Knodt, C. B.
1950. Ketosis and the Dairy Cow. Milk Plant Monthly 39: 76-77. Aug.
(180) Krukovsky, V. N.
1952. The Origin of Oxidized Flavors and Factors Responsible for their Development in Milk and Milk Products. Jour. Dairy Sci. 35 (1): 21-29.
(181) Krukovsky, V. N., and Guthrie, E. S.
1945. Ascorbic Acid Oxidation a Key Factor in the Inhibition or Promotion of the Tallowy Flavor in Milk. Jour. Dairy Sci. 28 (8): 565-579.
(182) Krukovsky, V. N., and Guthrie, E. S.
1946. Vitamin C, Hydrogen Peroxide, Copper and the Tallowy Flavor in Milk. Jour. Dairy Sci. 29 (5): 293-306.
(183) Krukovsky, V. N., and Herrington, B. L.
1942. Studies of Lipase action. VI. The Effect of Lipolysis Upon the Flavor Score of Milk. Jour. Dairy Sci. 25 (3): 237-239.

(184) Krukovsky, V. N., and Loosli, J. K.
1952. Studies on the Influence of Tocopherol Supplementation on the Vitamin Content of Milk Fat, Stability of Milk and Milk and Fat Production. Jour. Dairy Sci. 35 (10): 834-838.

(185) Krukovsky, V. N., Loosli, J. K., and Whiting, F.
1949. The Influence of Tocopherols and Cod Liver Oil on the Stability of Milk. Jour. Dairy Sci. 32 (3): 196-201.

(186) Krukovsky, V. N, and Sharp, P. F.
1938. Effect of Shaking on the Lipolysis of Cow's Milk. Jour. Dairy Sci. 21 (11): 671-682.

(187) Larsen, P. B., Gould, I. A., and Trout, G. M.
1941. Oxidation-Reduction Potentials and the Oxidized Flavor in Homogenized Milk. Jour. Dairy Sci. 24 (9): 789-793.

(188) Larsen, P. B., Trout, G. M., and Gould, I. A.
1941. Rancidity Studies on Mixtures of Raw and Pasteurized Homogenized Milk. Jour. Dairy Sci. 24 (9): 771-778.

(189) Leeder, J. G., and Herreid, E. O.
1940. The Relation of Bacteria and of Oxygen to the Flavor of Milk Susceptible to Becoming Oxidized. Vt. Agr. Expt. Sta. Bull. No. 457.

(190) Leeder, J. G., and Herreid, E. O.
1942. Relation of Ascorbic Acid and of Oxygen to Oxidized Flavor in Milk. Vt. Agr. Expt. Sta. Bull. No. 481.

(191) Leitch, R. H.
1934. Burnt or Caramel Flavors in Milk and Its Products. Scottish Jour. Agr. 17 (3): 293-296.

(192) Lindquist, H. G.
1942. Iodoform Flavor in Milk. Jour. Milk Tech. 5 (6): 334-355.

(193) Lindquist, H. G., and Donaldson, R. W.
1948. Benzene Hexachloride Flavored Milk - From Feeding Potatoes Grown on Soils Treated with the Chemical. Jour. Milk and Food Tech. 11 (6): 325-326.

(194) Lindsey, J. B.
1904. Distillery and Brewery By-Products. Mass. (Hatch) Agr. Expt. Sta. Bull. No. 94.

(195) Loosli, J. K., Krukovsky, V. N., Lofgreen, G. P., and Musgrove, R. B.
1950. The Comparative Value of Ladino Clover, Birdsfoot Trefoil, Timothy and Alfalfa for Yield and Quality of Milk. Jour. Dairy Sci. 33 (4): 228-236.

(196) Lucas, P. S.
1929. Many Factors Cause Abnormal Flavors. Mich. Agr. Expt. Sta. Qtr. Bull. 12: 18-20. Aug.

(197) MacCurdy, R. D., and Trout, G. M.
1940. The Effect of Holder and Flash Pasteurization on Some Flavors of Milk. II. The Effect on Corn and Alfalfa Silage Flavors. Jour. Dairy Sci. 23 (9): 855-860.

(198) MacCurdy, R. D., and Trout, G. M.
1940. The Effect of Holder and Flash Pasteurization on Some Flavors of Milk. I. The Effect on Miscellaneous Flavors Common to Commercial Raw Milk. Jour. Dairy Sci. 23 (9): 843-860.

(199) MacDonald, Margaret B., Andes, Esther, and Briggs, Frances A.
1930. The Effect of the Mineral Oil Treatement on the Composition of Milk. Jour. Home Econ. 22 (3): 213-218.

(200) MacDonald, Margaret B., and Crawford, Ester M.
1927. The Removal of the Onion or Garlic Flavor and Odor from Milk. Jour. Home Econ. 19 (2): 65-69.
(201) MacDonald, Margaret B., and Crawford, Ester M.
1927. Removal of Onion or Garlic Flavor and Odor from Milk. Tenn. Agr. Expt. Sta. Cir. No. 14.
(202) MacDonald, Margaret B., and Glaser, Adelaide.
1929. The Removal of the Bitter Flavor from "Bitterweed" Cream. Tenn. Agr. Expt. Sta. Cir. No. 26.
(203) MacDonald, Margaret B., and Jacob, M.
1928. Inhalation the Chief Factor in Onion or Garlic Contamination of Milk. Sci. 68: 568.
(204) Marquardt, J. C.
1932. Bleaching and Cardboard Flavor in Milk. The Milk Dealer 22 (3): 39-40.
(205) Marquardt, J. C.
1946. The Relationship of Sediment to the Flavor of Milk. Jour. Milk Tech. 9 (1): 5-11.
(206) Marquardt, J. C., and Dahlberg, A. C.
1934. Pasteurized Milk Flavor and Creaming Power as Affected by Heating Medium Temperatures and Pasteurizer Linings. N. Y. Agr. Expt. Sta. Tech. Bull. No. 223.
(207) Marryatt, E. R.
1938. Farm Control of Feed Flavors. N. Z. Jour. Agr. 57: 303-304. Oct.
(208) Marshall, C. E.
1902. Aeration of Milk. Mich. Agr. Expt. Sta. Spec. Bull. No. 16.
(209) Martin, W. H.
1937. Plant Processing and Control Methods in Preventing Oxidized Flavor. The Milk Dealer 27 (2): 88.
(210) Martin, W. H., Cave, H. W., Whitnah, C. H., Beck, G. H., and Atkeson, F.W.
1940. The Effect of Feeding Vitamin A and Carotene to Cows on the Flavor and Color of Their Milk. Int. Assoc. Milk Dealers Bull. 12: 279-286.
(211) Mattick, A. T. R.
1927. Oiliness in Milk. Jour. Agr. Sci. 17 (3): 388-391.
(212) Miscall, J., Cavanaugh, G. W., and Carodemos, P. P.
1929. Copper in Dairy Products and Its Solution Under Various Conditions. Jour. Dairy Sci. 12 (5): 379-384.
(213) Moore, A. V., and Trout, G. M.
1946. Detection of Raw Milk Contamination in Homogenized Milk by Means of the Phosphatase Test, and by Organoleptic Examination. Mich. Agr. Expt. Sta. Qtr. Bull. 28 (4): 311-316.
(214) Moore, A. V., and Trout, G. M.
1947. High Viscosity and Progressive Thickening of Homogenized Milk. Mich. Agr. Expt. Sta. Qtr. Bull. 29 (3): 177-187.
(215) Mull, L. E., and Fouts, E. L.
1947. Some Observations on the Use of Roccal. Jour. Milk and Food Tech. 10 (2): 102-104.

(216) Nelson, D. H., and Dahle, C. D.
1939. Similarity of the Oxidized Flavor From Three Sources. The Milk Dealer 29 (1): 62-66.

(217) Nelson, D. H., and Dahle, C. D.
1940. The Relation of Iodine and Peroxide Numbers to Oxidized Flavor of Milk. Jour. Dairy Sci. 23 (5): 391-398.

(218) Nelson, D. H., and Dahle, C. D.
1940. Enzymes and Other Substances as Antioxidants in Milk. The Milk Dealer 29 (10): 41-55.

(219) Nelson, J. A.
1944. "Barny" Flavor in Milk. The Goat World. 29 (11): 24-25.

(220) Nelson, J. A.
1943. The Flavor of Market Milk as Influenced by Pasteurization. Mont. Agr. Expt. Sta. Bull. No. 410.

(221) Nevens, W. B., and Tracy, P. H.
1928. The Relation of Soybean Hay and Ground Soybeans to Flavor and Composition of Milk and Butter. Jour. Dairy Sci. 11 (11): 479-487.

(222) Newman, R. W.
1930. Pseudomonas as a Cause of Bitter Milk. Calif. Dept. Agr. Bull. No. 19: 640.

(223) Okuyama, S.
1927. The Bottle Cap Not to Blame. The Milk Dealer 16 (11): 45.

(224) Olson, F. C., and Brown, W. C.
1942. Oxidized Flavor in Milk. XI. Ascorbic Acid, Glutathione and Hydrogen Peroxide as Mechanisms for the Production of Oxidized Flavor. Jour. Dairy Sci. 25 (12): 1027-1039.

(225) Olson, F. C., and Brown, W. C.
1944. Oxidized Flavors in Milk. XIII. Studies of Cupric Complexes of Ascorbic Acid and Certain Amino Acids and Their Possible Relationship to Oxidized Flavor Development in Milk. Jour. Dairy Sci. 27 (3): 197-204.

(226) Olson, F. C., and Brown, W. C.
1944. Oxidized Flavor in Milk. XIV. A Possible Mode of Action of Inhibitors in Preventing the Development of Oxidized Flavor in Milk. Jour. Dairy Sci. 27 (3): 205-213.

(227) Olson, T. M. , Totman, C. C., and Wallis, G. C.
1936. Effect of Tankage on the Flavor of Milk. Jour. Dairy Sci. 19 (5): 313-315.

(228) Paley, C.
1942. Chemical Taste in Milk. Jour. Milk Tech. 5 (3): 165.

(229) Palmer, L. S.
1922. Is Lipase a Normal Constituent of Cow's Milk? Jour. Dairy Sci. 5 (1): 51-62.

(230) Palmer, L. S.
1922. Bitter Milk of Advanced Lactation. A Lipase Fermentation. Jour. Dairy Sci. 5 (2): 201-211.

(231) Patton, S., and Josephson, D. V.
1949. The Isolation of Furfuryl Alcohol from Heated Skim Milk. Jour. Dairy Sci. 32 (3): 222-227.

(232) Patton, S., and Josephson, D. V.
1949. Observations on the Application of the Nitroprusside Test to Heated Milk. Jour. Dairy Sci. 32 (5): 398-405.

(233) Petersen, W. E., and Brereton, J. G.
1942. Effect of Inhaled Substances on Milk Flavors. Jour. Dairy Sci. 25 (5): 381-387.

(234) Pratt, A. D.
1944. Peppergrass Silage. Jour. Dairy Sci. 27 (5): 365-367.

(235) Procter, F.
1926. Chamomile (Mayweed) and a Taint in Milk. Jour. Agr. Sci. 16: 443-450. July.

(236) Quam, G. N.
1929. Solubility of Metals in Milk. Ind. Eng. Chem. 21 (7): 703-704.

(237) Quam, G. N., and Solomon, E. I.
1927. Some More Facts About Metals. The Milk Dealer 16 (5): 61-62.

(238) Quam, G. N., Solomon, E. I., and Hellvig, A.
1928. Influence of Temperature on Rate of Corrosion of Copper by Milk. Ind. Eng. Chem. 20 (9): 930-931.

(239) Ramsey, R. J., and Tracy, P. H.
1933. Rancid Flavors in Raw Milk. Milk Plant Monthly 22 (5): 44-45,48.

(240) Reder, Ruth.
1938. The Chemical Composition and Properties of Normal and Rancid Jersey Milk. I. Chloride and Lactose Content. Jour. Dairy Sci. 21 (4): 199-210.

(241) Reder, Ruth.
1938. The Chemical Composition and Properties of Normal and Rancid Jersey Milk. II. Fat, Total Solids and Protein Content. Jour. Dairy Sci. 21 (6): 249-261.

(242) Reder, Ruth.
1938. The Lipase, Fatty Acid, and Cholesterol Content of Cow's Blood in Relation to the Production of Rancid Milk. Jour. Dairy Sci. 21 (8): 475-480.

(243) Reece, T.
1912. Sugar Beet Feed for Milch Cows. Hoard's Dairyman 44 (2): 597.

(244) Reid, W.H. E.
1927. The Deleterious Effect of Freezing on Several of the Physical Properties of Milk. Mo. Agr. Expt. Sta. Res Bull. No. 100.

(245) Rice, F. E.
1926. Sweetened Condensed Milk. V. Rancidity. Jour. Dairy Sci. 9 (3): 293-305.

(246) Rice, F. E., and Markley, A. L.
1922. Proof of the Presence of Lipase in Milk and a New Method for the Detection of the Enzyme. Jour. Dairy Sci. 5 (1): 64-80.

(247) Rice, F. E. and Miscall, J.
1923. Copper in Dairy Products and Its Solution in Milk Under Various Conditions. Jour. Dairy Sci. 6: 261-277. July.

(248) Roadhouse, C. L.
1937. Experiences in Meeting Milk Flavor Problems. 25th Ann. Rept. Int. Assoc. Dairy and Milk Inspectors. (pp. 201-209).

(249) Roadhouse, C. L.
1930. The Status of Flavors in Milk. 19th Ann. Rept. Int. Assoc. Dairy and Milk Inspectors (pp. 246-253.)

(250) Roadhouse, C. L., and Henderson, J. L.
1932. The Relation of the Soluble Portion of Alfalfa to the Rapid Absorption of Feed Flavor in Milk. Jour. Dairy Sci. 15 (4): 299-302.

(251) Roadhouse, C. L., and Henderson, J. L.
1935. Flavors of Milk and their Control. Calif. Agr. Expt. Sta. Bull. No. 595.

(252) Roadhouse, C. L., and Henderson, J. L.
1937. Regulating the Feeding of Certain Roughages to Minimize Their Influence on the Flavor of Milk. Jour. Dairy Sci. 20 (10): 679-683.

(253) Roadhouse, C. L., and Henderson, J. L.
1936. Flavors of Milk Influenced by Different Systems of Feeding Certain Roughages. Proc. 29th Ann. Conv. Int. Assoc. Milk Dealers Lab. Sec. (pp. 135-141.)

(254) Roadhouse, C. L., and Henderson, J. L.
1930. The Influence of Molasses and Sodium Chloride in Dairy Rations on the Lactose and Chloride Content and Taste of Milk. Jour. Dairy Sci. 13 (2): 117.

(255) Roadhouse, C. L., and Koestler, G. A.
1929. Contribution to the Knowledge of the Taste of Milk. Jour. Dairy Sci. 12 (6): 421-437.

(256) Roberts, W. M., and Wylie, C. E.
1945. Off-Flavor in Milk. Tenn. Agr. Expt. Sta. Cir. No. 91.

(257) Roland, C. E., Sorensen, C. M., and Whitaker, R.
1937. A Study of Oxidized Flavor in Commercial Pasteurized Milk. Jour. Dairy Sci. 20 (4): 213-218.

(258) Roland, C. T., and Trebler, H. A.
1937. The Effect of Fat Content on Oxidized Flavor in Milk and Cream. Jour. Dairy Sci. 20 (6): 345-350.

(259) Ross, H. E.
1937. Homogenization as a Preventive of Oxidized Flavor. Milk Plant Monthly 26 (4) and (5): 36-39, 40-44.

(260) Ruehle, G. L. A.
1930. Keeping Qualities of Butter. Mich. Agr. Expt. Sta. Tech. Bull. No. 102.

(261) Russell, H. L.
1897. Tainted or Defective Milks: Their Causes and Methods of Prevention. Wis. Agr. Expt. Sta. Bull. 62.

(262) Russell, H. L.
1897. Tainted or Defective Milk: Their Causes and Methods of Prevention. Wis. Agr. Expt. Sta. Bull. No. 62.

(263) Russell, O. M., and Dahle, C. D.
1943. The Prevention of Oxidized Flavor in Milk and Ice Cream by the Use of Concentrated Milk Products. Jour. Dairy Sci. 26 (1): 25-35.

(264) Sadler, W.
1929. Flavor Defects in High Grade Milk. Scientific Agr. 10 (2): 111-119.

(265) Sadler, W., Irwin, M. L., and Golding, N. S.
1929. An Alleged "Feed" Flavor in Milk Caused by Specific Bacteria. Milk Dealer 19 (3): 73-75, 117-122.

(266) Sharp, P. F., Hand, D. B., and Guthrie, E. S.
1940. Preliminary Report on the Deaeration of Market Milk. Jour. Milk Tech. 3 (3): 137-143.

(267) Sharp, P. F., Hand, D. B., and Guthrie, E. S.
1940. Supplementary Notes on the Deaeration of Milk. Jour. Milk Tech. 3 (4): 228-229.

(268) Sharp, P. F., Hand, D. B., and Guthrie, E. S.
1942. Experimental Work on Deaeration of Milk. Inter. Assoc. Milk Dealers Bull. 17: 365-375.

(269) Sharp, P. F., Trout, G. M., and Guthrie, E. S.
1936. Vitamin C, Copper and the Oxidized Flavor of Milk. 10th Ann. Rept. N. Y. State Assoc. of Dairy and Milk Inspectors (pp. 153-164.)

(270) Shaw, J. C.
1946. What Do We Know About Ketosis in Dairy Cattle. Guernsey Breeders' Jour. 69 (10): 1316.

(271) Sheuring, J. J., Marden, R. A., Morrison, S. H., and Deal, J. F.
1952. Flavor of Milk as Affected by Grazing Cows on Ladino Clover. Southern Dairy Products Jour. 51 (5): 34, 39, 46-48, 62-64.

(272) Snell, R.
1921. Fruity Flavours in Milk and Cheese. Queensland Agr. Jour. 16 (1): 19-20.

(273) Sommer, H. H., and Gebhardt, H. T.
1930. Copper Equipment Injures Milk and Dairy Products. Wis. Agr. Expt. Sta. Bull. No. 410.

(274) Spur, B.
1943. The Relationship Between the Temperature of Pasteurization (Holding Method) and the Appearance of Cooked Flavor in Homogenized Milk. Jour. Milk Tech. 6 (2): 86-88.

(275) Stull, J. W., Herreid, E. O., and Tracy, P. H.
1948. A Study of the Use of the Antioxidant Nordihydroguaiaretic Acid in Dairy Products. I. Its Antioxygenic Properties in Milk. Jour. Dairy Sci. 31 (6): 449-453.

(276) Swanson, A. M., and Sommer, H. H.
1940. Oxidized Flavor in Milk. I. Effect of the Development of Oxidized Flavor on the Iodine Number of the Phospholipid Fraction of Milk. Jour. Dairy Sci. 23 (3): 201-208.

(277) Swanson, A. M., and Sommer, H. H.
1940. Oxidized Flavor in Milk. II. The Relation of Oxidation-Reduction Potentials to Its Development. Jour. Dairy Sci. 23 (7): 597-614.

(278) Tarassuk, N. P.
1942. The Problem of Controlling Rancidity in Milk. Milk Plant Monthly 31: 24-25. April.

(279) Tarassuk, N. P., and Henderson, J. L.
1942. Prevention of Development of Hydrolytic Rancidity in Milk. Jour. Dairy Sci. 25 (9): 801-806.

(280) Tarassuk, N. P., and Jack, E. L.
1949. Lipolytic Flavors of Milk. Milk Plant Monthly 38 (10): 48.

(281) Tarassuk, N. P., and Roadhouse, C. L.
1951. The Effect of Dried Citrus Products on the Flavor of Milk. Milk Plant Monthly. 40: 38-39. Sept.

(282) Thatcher, R. W., and Dahlberg, A. C.
1917. Enzymes of Milk and Butter. Jour. Agr. Res. 11 (9): 437-450.
(283) Thurston, L. M.
1937. Oxidized Flavor in Milk. The Milk Dealer 26 (9): 112-118.
(284) Thurston, L. M.
1935. Oxidized Flavor in Milk. Proc. 28th Ann. Conv. Internat. Assoc. Milk Dealers Lab. Sec. (pp. 121-141.)
(285) Thurston, L. M.
1937. Theoretical Aspects of the Causes of Oxidized Flavor Particularly from the Lecithin Angle. Proc. 30th Ann. Conv. Int. Assoc. Milk Dealers Lab. Sec. (pp. 143-153.)
(286) Thurston, L. M., and Barnhart, J. L.
1935. A Study of the Relation of Materials Adsorbed on the Fat Globules to the Richness of Flavor of Milk and Certain Milk Products. Jour. Dairy Sci. 18 (2): 131-137.
(287) Thurston, L. M., Brown, W. C., and Dustman, R. B.
1936. Oxidized Flavor in Milk. II. The Effects of Homogenization, Agitation and Freezing of Milk on Its Subsequent Susceptibility to Oxidized Flavor Development. Jour. Dairy Sci. 19 (11): 671-682.
(288) Thurston, L. M., Brown, W. C., and Dustman, R. B.
1935. Oxidized Flavor in Milk. I. The Probable Relation of Lecithin to Oxidized Flavor. Jour. Dairy Sci. 18 (5): 301-306.
(289) Thurston, L. M., and Olson, H. C.
1933. The Bacterial Flavor of High-grade Milk Before and After Pasteurization. W.Va. Expt. Sta. Bull. No. 255.
(290) Tomlinson, A. S.
1940. A Study of Oxidized Flavor. Amer. Milk Rev. 2 (2): 34-35.
(291) Tracy, P. H.
1931. What Causes "Cappy" Flavor in Milk? The Milk Dealer 21 (1): 68-69.
(292) Tracy, P. H.
1938. Problems in the Processing and Marketing of Homogenized Milk. 12th Ann. Rept. N. Y. State Assoc. Dairy and Milk Inspectors (pp. 69-84.)
(293) Tracy, P. H.
1936. Factors Responsible for Off Flavors in Milk. The Milk Dealer 25 (8): 114-116.
(294) Tracy, P. H., and Ramsey, R. J.
1931. Malt Flavor in Raw Milk Produced by Micrococcus. Jour. Dairy Sci. 14 (9): 457-462.
(295) Tracy, P. H., Ramsey, R. J., and Ruehe, H. A.
1933. Certain Biological Factors Related to Tallowiness in Milk and Cream. Ill. Agr. Expt. Sta. Bull. 389: 579-594.
(296) Tracy, P. H., and Ruehe, H. A.
1931. The Relation of Certain Plant Processes to Flavor Development in Market Milk. Jour. Dairy Sci. 14 (3): 250-267.
(297) Trebler, H. A., Wesley, W. A., and LaQue, F. L.
1932. Corrosion of Metals by Milk. Effects of Operating Conditions on Corrosion in Various Parts of Pasteurizing Equipment. Ind. Eng. Chem. 24 (3): 339-350.
(298) Trout, G. M.
1927. Garlic and Wild Onion Troubles. The Dairy Farmer 25: 14. July.

(299) Trout, G. M., and Gjessing, E. C.
1939. Ascorbic Acid and Oxidized Flavor in Milk. I. Distribution of Ascorbic Acid and Occurrence of Oxidized Flavor in Commercial Grade A Raw, in Pasteurized Irradiated, and in Pasteurized Milk Throughout the Year. Jour. Dairy Sci. 22 (4): 271-281.

(300) Trout, G. M., and Gould, I. A.
1938. Homogenization as a Means of Stabilizing the Flavor of Milk. Mich. Qtr. Bull. 21 (1): 21-31.

(301) Trout, G. M, and Harwood, R. E.
1944. Influence of Balbo-Rye Pasture or the Odor of Milk. Mich. Agr. Expt. Sta. Qtr. Bull. 27: 39-47. Aug.

(302) Trout, G. M., McGee, C. R., and Harrison, C. M.
1940. Effect of Alfalfa- Bromegrass Pasture on the Flavor of Milk When the Cows are Milked Three Times Daily. Mich. Agr. Expt. Sta. Qtr. Bull. 22 (3): 163-174.

(303) Trout, G. M., and McMillan, D. Y.
1943. Absorption of Odors by Milk. Mich. Agr. Expt. Sta. Tech. Bull. No. 181.

(304) Trout, G. M., and Scheid, M. V.
1941. The Influence of the Time and Temperature of Homogenization on Certain Properties of the Milk. Mich. Agr. Expt. Sta. Qtr. Bull. 24.

(305) Trout, G. M., and Sharp, P. F.
1937. The Reliability of Flavor Judgements, with Special Reference to the Oxidized Flavor of Milk. N. Y. (Cornell) Agr. Expt. Sta. Memo. No. 204.

(306) Trout, G. M., and Taylor, G. E.
1935. The Effect of Beet Tops on the Flavor and Odor of Milk. Mich. Agr. Expt. Sta. Qtr. Bull. 18: 37-45.

(307) Weathers, Norabelle D.
1933. The Determination of the Bitter Substance in "Bitterweed" Milk. Jour. Dairy Sci. 16 (4): 401-403.

(308) Weaver, E., Kuhlman, A. H., and Fouts, E. L.
1935. The Effect of Alfalfa Hay on Milk Flavor. Jour. Dairy Sci. 18 (1): 55-61.

(309) Webb, R. E., and Hileman, J. L.
1937. The Relation of the Oxidation-Reduction Potential of Milk to Oxidized Flavor. Jour. Dairy Sci. 20 (1): 47-57.

(310) Weckel, K. G., and Jackson, H. C.
1936. Observations on the Source of Flavor in Milk Exposed for Prolonged Periods to Radiation. Food Research 1 (5): 419-426.

(311) Weckel, K. G., Jackson, H. C., Haman, R., and Steinback, H.
1936. Reveal Factors Responsible for Unusual Flavors in Irradiated Milk. Wis. Agr. Expt. Sta. Bull. No. 435.

(312) Weinstein, B. R.
1951. A Study of Human Milk With Special Reference to the Oxidized Flavor Development . Milk Plant Monthly 40 (11): 30-31.

(313) Weinstein, B. R., Duncan, C. W., and Trout, G. M.
1951. The Solar-Activated Flavor of Homogenized Milk. IV. Isolation and Characterization of a Whey Constituent Capable of Producing the Solar-Activated Flavor. Jour. Dairy Sci. 34 (6): 570-576.

(314) Weinstein, B. R., Lillevik, H. A., Duncan, C. W., and Trout, G. M.
1951. The Solar-Activated Flavor of Homogenized Milk. V. The Electrophoretic Analysis of a Contributing Minor-Protein Fraction. Jour. Dairy Sci. 34 (8): 784-789.

(315) Weinstein, B. R., Lowenstein, M., and Olson, H. C.
1940. The Use of Ascorbic Acid in Controlling Oxidized Flavor in Milk. Milk Plant Monthly 37 (10): 116-117.

(316) Weinstein, B. R., and Trout, G. M.
1951. The Solar-Activated Flavor of Homogenized Milk. I. Susceptibility of Individual Cow's Milk. Jour. Dairy Sci. 34 (6): 554-558.

(317) Weinstein, B. R., and Trout, G. M.
1951. The Solar-Activated Flavor of Homogenized Milk. II. The Role of Oxidation and the Effectiveness of Certain Treatments. Jour. Dairy Sci. 34 (6): 559-564.

(318) Weinstein, B. R., and Trout, G. M.
1951. The Solar-Activated Flavor of Homogenized Milk. III. Effect of Deaeration, Surface Area of Fat Globules and Relation of the Kreis Test. Jour. Dairy Sci. 34 (6): 565-569.

(319) Weinstein, B. R., and Trout, G. M.
1950. Susceptibility of Milk from Various Dairy Breeds to Homogenization - Induced Rancidity. Mich. Agr. Expt. Sta. Qtr. Bull. 32 (3): 311-317.

(320) Whitehead, H. R.
1930. The Reduction of Methylene Blue in Milk - The Influence of Light. Biochem. Jour. 24 (3): 579-584.

(321) Whitehead, H. R.
1931. The Influence of Sunlight on Milk. Biochem. Jour. 25 (5): 1647-1652.

(322) Whitnah, C. H., Peterson, W. J., Atkeson, F. W., and Cave, H. W.
1939. Carotene Balance and Blood-Carotene Levels in Heifers and Lactating Dairy Cows, and Their Relation to the Production of Off-Flavor Milk. Jour. Agr. Res. 58 (5): 317-355.

(323) Willard, H. S., and Gilbert, C. S.
1953. Influence of Dairy Equipment on Copper Content and Intensity of Oxidized Flavor in Milk, Cream, and Skimmilk. Milk Dealer 42 (6): 46, 66-67.

(324) Wing, H. H., and Anderson, L.
1900. Sugar Beet Pulp as a Food for Cows. Cornell Univ. Agr. Expt. Sta. Bull. No. 183.

(325) Woll, F. W., and Humphrey, G. C.
1904. Soybean Silage as a Food for Dairy Cows. Wis. Agr. Expt. Sta. 21st Ann. Rept. (pp. 67-74.)

(326) Wolman, I. J.
1941. Remarks on Homogenized Milk. Int. Assoc. Milk Dealers Bull. 20: 546-550.

(327) Woodward, T. E., Turner, W. F., and Griffiths, D.
1915. Prickly Pears as a Feed for Dairy Cows. Jour. Agr. Res. 4: 405. Aug.

(328) Wright, T. H.
1923. Pasteurization of Market Milk in the Glass Enamel Tank and in the Bottle. S. Dak. Expt. Sta. Bull. No. 203.

(329) Wylie, C. E.
1937. Control of Onion Flavors in Milk. The Milk Dealer 27: 84. Oct.

(330) Yale, M. W.
1934. The Quality of Milk Pasteurized by HTST and 30 Minute Holding Methods. 22nd Ann. Rept. Int. Assoc. Dairy and Milk Inspectors (pp. 62-66.)